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FEASIBILITY OF HYDRAULIC TRANSPORT OF GROUND HOUSEHOLD REFUSE THROUGH SEWER APPURTENANCES

David A. Monaghan, et al

Foster-Miller Associates, Incorporated

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An investigation to determine the feasibility of hydraulic transport of ground refuse in sanitary sewers of conventional design. For hydraulic transport, the material of household refuse is ground in an automatic household grinder, mixed with nonfecal household sewage water, and introduced into the main sewer through the standard service connection. The slurry flows through the sewers under gravity. It was concluded that hydraulic transport of ground refuse in gravity sewers at concentrations of 1.0 percent is feasible. At very low velocities small pressure drops may occur at various appurtenances but are not sugnificant relative to the overall head. At flow velocities of 2.5 feet per second and above these losses are negligible.

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a ficus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

studies on the effects of environmental contaminants on man and the biosphere, and

a search for ways to prevent contamination and to recycle valuable resources.

As part of these activities, the study described here presents an investigation to determene the feasibility of hydraulic transport of ground refuse in sanitary sewers of conventional design.

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ABSTRACT

An investigation was undertaken to determine the feasibility of hydraulic transport of ground refuse in sanitary sewers of conventional design. An earlier study established the feasibility of hydraulic transport through straight sections of sewer. This study extends the feasibility investigation to the hydraulic transport of ground refuse through bends, stilling basins, overflow wiers, inverted siphons, lift stations, and similar appurtenances encountered in normal sewer design practice.

For hydraulic transport, the paper, glass and aluminum content of individual household refuse is ground in a specially designed automatic household grinder, mixed with the non-fecal portion of the household sewage water, and introduced into the main sewer through the standard service connection. The ground refuse slurry flows through the sewers under gravity.

A preliminary investigation indicated that the surface characteristics of the pipe and the quality of the water did not significantly affect the results of the study. Hence, to aid flow visualization, the test loop was fabricated from glass pipe and operated with clear water for the majority of the tests. Various concentrations of ground refuse were added to determine:

(a) the minimum flow rate at which the refuse slurry can be satisfactorily transported through the sewer system appurtenances.

(b) the types or classes of materials deposited or expected to be deposited in the pipe system and its appurtenances.

(c) modifications in the design of the appurtenances necessary to minimize deposition of material or other conditions leading to unsatisfactory flow.

It was concluded that in general, hydraulic transport of ground refuse in gravity sewers at concentrations of 1.0 percent is feasible. At very low velocities small pressure drops may occur at various appurtenances but these are not significant relative to the overall head available. At flow velocities of 2.5 feet per second and above these losses are negligible.

TABLE OF CONTENTS

	Page No.
SUMMARY	viii
CHAPTER 1 - INTRODUCTION	1
General	1
Summary of Previous Investigation	3
Objective	6
Scope of Program	7
CHAPTER 2 - EXPERIMENTAL PROGRAM TO STUDY FLOW CHARACTERISTICS OF GROUND REFUSE SLURRY	8
Objective and Scope of Experimental Program	8
Hydraulic Test Facility	8
Characteristics of Domestic Refuse and Heavy Solids	10
Types of Tests and Procedures	13
Range of Test Parameters	15
CHAPTER 3 - INVERTED SIPHON EVALUATION	18
Experimental Facility and Test Procedures	18
Experimental Head Loss Results	25
Experimental Scouring Velocity Results	32
Conclusions	35
CHAPTER 4 - RUNNING TRAP EVALUATION	37
Experimental Facility and Test Procedures	37
Experimental Head Loss Results	41
Experimental Scouring Velocity Test Results	47
CHAPTER 5 - ELBOW EVALUATION	50
Experimental Facility and Test Procedures	50
Experimental Head Loss Results	50
Experimental Scouring Velocity Test Results	58
CHAPTER 6 - MANHOLE EVALUATION	61
Experimental Facility and Test Procedures	61
Experimental Head Loss Results	71

TABLE OF CONTENTS (CONT.)

	Page No.
Experimental Scouring Velocity Results	77
CHAPTER 7 - PIPE JUNCTION FLOW EVALUATION	80
Experimental Facility and Test Procedure	80
Experimental Head Loss Results	85
Scouring Velocity Tests	85
CHAPTER 8 - PUMP INLET FLOW EVALUATION	91
Experimental Facility and Preparation	91
Experimental Procedures	91
Pump Inlet Conclusions	95
CHAPTER 9 - FLOW EVALUATION IN STILLING BASINS, OVERFLOW WEIRS AND OBSTACLES	96
Experimental Facility and Test Procedure	96
Conclusions Regarding Flow Around Obstacles	100
CHAPTER 10 - SUMMARY OF RESULTS AND CONCLUSIONS	103
Summary of Results	103
Conclusions	104
CHAPTER 11 - RECOMMENDATIONS	106
APPENDIX A	107
BIBLIOGRAPHY	123

LIST OF ILLUSTRATIONS

Figure No.		Page No.
1	Schematic Diagram Hydraulic Test Facility	9
2	Heavy Solids Feeder	11
3	Static Pressure Tap and Manometer Installation	14
4	Typical Twin Barrel Siphon System	19
5	Inverted Siphon for Combined Sewage Flow	20
6	Inverted Siphon Test Loop	21
7	45° Inverted Siphon Test Facility	22
8	60° Inverted Siphon Test Facility	23
9	Submerged Siphon Discharge	24
10	Heavy Solids Accumulation for Scouring Characteristics Determination	26
11	Head Loss Characteristics for the 22 1/2° Inverted Siphon	27
12	Head Loss Characteristics for 45° Inverted Siphon	28
13	Head Loss Characteristics for 60° Inverted Siphon	29
14	Effect of Siphon Angle on Head Loss - Clear Water	30
15	Effect of Siphon Angle on Head Loss - 1.1 Percent Refuse Concentration	31
16	A Typical Drainage System Connecting Building to Sewer	38
17	Flow Facility for Running Trap Tests	39
18	Running Trap Installation	40
19	Head Loss Characteristics for Running Trap - Clear Water	42

LIST OF ILLUSTRATIONS (CONT.)

Figure No.		Page No.
20	Head Loss Characteristic For Running Trap 0.5 Percent Refuse	43
21	Head Loss Characteristic for Running Trap - 1.0 Percent Refuse	44
22	Head Loss Characteristic for Running Trap - 1.5 Percent Refuse	45
23	22 1/2° and 45° Elbow Test Loop Diagram	51
24	90° Elbow Test Loop Diagram	52
25	Elbow Installations in Test Loop	53
26	Head Loss Characteristics for 22 1/2° Elbow	54
27	Head Loss Characteristics for 45° Elbow	55
28	Head Loss Characteristics for 90° Elbow	56
29	Cutaway View of Simulated Size Transition Manhole	62
30	Manhole Bench and Channel Inserts	63
31	Flow Loop for Straight Manhole Tests	65
32	Flow Loop for 90° Bend Manhole Tests	66
33	Straight Channel Manhole Model	67
34	Size Transition Manhole Model	68
35	90° Bend Manhole Model	69
36	Definition of Manhole Geometry Symbols	71
37	Head Loss Characteristics for Straight Manhole	73
38	Head Loss Characteristics for 90° Bend Manhole	74
39	Head Loss Characteristics for Size Transition Manhole	75
40	Flow Loop for Tee Junction Tests	81

LIST OF ILLUSTRATIONS (CONT.)

Figure No.		Page No.
41	Junction Flow Test Facility	82
42	Nomenclature for Energy Balance in Junction	84
43	Tee Junction Head Loss Results	86
44	Wet Well Design for Pump Inlet Tests	92
45	Pump Inlet Configuration for Flow Study	93
46	Simulated Wet Well for Flow Facility	94
47	Installation of Lucite Channel in Flow Loop	97
48	Detail of Flow in Lucite Tank	98
49	Lucite Channel for Flow Visualization	99
50	Variation in Flow Pattern Upstream of the Overflow Wier	101
A-1	Detail of Rigid Foam Insert for Straight Thru Manhole	108
A-2	Detail of Rigid Foam Insert for 90° Bend Manhole	109
A-3	Detail of Rigid Foam Insert for Size Transition Manhole	110
A-4	Head Loss Data for Straight Channel Manhole, Clear Water	111
A-5	Head Loss Data for Straight Channel Manhole, 0.5 Percent Refuse	112
A-6	Head Loss Data for Straight Channel Manhole, 1.1 Percent Refuse	113
A-7	Head Loss Data for Straight Channel Manhole, 1.5 Percent Refuse	114
A-8	Head Loss Data for 90° Bend Manhole, Clear Water	115
A-9	Head Loss Data for 90° Bend Manhole, 0.5 Percent Refuse	116

LIST OF ILLUSTRATIONS (CONT.)

Figure No.		Page No.
A-10	Head Loss Data for 90° Bend Manhole, 1.1 Percent Refuse	117
A-11	Head Loss Data for 90° Bend Manhole, 1.5 Percent Refuse	118
A-12	Head Loss Data for Size Transition Manhole, Clear Water	119
A-13	Head Loss Data for Size Transition Manhole, 0.5 Percent Refuse	120
A-14	Head Loss Data for Size Transition Manhole, 1.1 Percent Refuse	121
A-15	Head Loss Data for Size Transition Manhole, 1.5 Percent Refuse	122

LIST OF TABLES

Table No.		Page No.
I	CHARACTERISTICS OF HEAVY SOLIDS USED IN TEST PROGRAM	12
II	TYPICAL HEAVY SOLID CONTENT OF HOUSEHOLD REFUSE	16
III	SCOURING VELOCITY DATA (A)	33
IV	SCOURING VELOCITY DATA	34
V	AVERAGE HEAD LOSS FACTOR, k_t, FOR RUNNING TRAP	46
VI	SCOURING VELOCITY OF RUNNING TRAP	48
VII	HEAD LOSS COEFFICIENTS FOR ELBOWS	57
VIII	SCOURING VELOCITY TESTS - ELBOW EVALUATION	59
IX	SLOPE COMBINATIONS FOR STRAIGHT CHANNEL AND SIZE TRANSITION CHANNEL TESTS	70
X	SLOPE COMBINATIONS FOR 90° BEND MANHOLE TESTS	70
XI	AVERAGE HEAD LOSS COEFFICIENTS FOR MANHOLE FLOWS	76
XII	MANHOLE SCOURING VELOCITY SUMMARY	79
XIII	HEAD LOSS COEFFICIENT FOR TEE	87
XIV	SUMMARY OF JUNCTION TEE SCOURING DATA	89

SUMMARY

This program conducted for the Office of Research and Monitoring, Solid Waste Research, Environmental Protection Agency, was designed to experimentally investigate the gravity flow of ground household refuse through a wide range of sewer appurtenances. These included inverted siphons, running traps, bends, manholes, pump well inlets, lift stations and obstacles. It was conducted under Contract No. 68-03-0095. This report presents a description of the experimental facility and the testing procedures in addition to a summary of the results of the investigation.

The objective of the program discussed in this report is to extend the feasibility study of hydraulic transport of ground refuse in sanitary sewers of conventional design. Key factors considered in evaluating the feasibility are:

(1) The minimum flow rate of which refuse slurry can be satisfactorily transported through the pipe system and its appurtenances.

(2) The rates, types, and classes of material deposited or expected to be deposited in the pipe system and its appurtenances.

(3) Modifications in the design of the appurtenances necessary to minimize deposition of material or other conditions leading to unsatisfactory flow.

The hydraulic flow, under gravity, of ground refuse slurry through sewer appurtenances was investigated in an experimental test loop set up in our laboratory. Tests were run using 22 1/2°, 45°, and 60° inverted siphons; a running trap; 45°, 60° and 90° horizontal bends; straight, size transition and 90° bend manhole configurations; a tee junction; a typical pump inlet design; and several obstacles typical of sewage flow situations.

The investigation showed that the hydraulic transport of ground refuse at concentrations up to 1.0 percent is feasible. At very low velocities small head losses may occur at specific appurtenances but these are not significant relative to the total head available. At flow velocities above 2.5 feet per second and above, these head losses become negligible.

At refuse concentrations on the order of 0.5 percent, head losses in the appurtenances were frequently reduced from the clear water case, indicating improved flow characteristics at these low concentrations. This is in agreement with the results obtained in previous studies for straight pipe flow.

At a refuse concentration of 1.5 percent, however, significant increases in pressure drop were noted for the appurtenances tested. It appears, therefore, that 1.0 percent refuse is the upper limit for refuse slurry flow through existing sewers.

At specific locations -- the third elbow of inverted siphons and the outlet pipe of manholes -- heavy solids accumulate unless velocities considerably higher than the 2.5 feet per second design minimum are present to aid in scouring. These accumulations do not appear to present a critical problem since they both reach a steady state height before any possibility of blockage occurs. Scouring in the siphon which flows full is aided by the increase in local velocity at the pile due to the restricted flow area. As the pile grows, the local velocity also increases until the required scouring velocity is reached. For the manhole outlet the accumulation stretches downstream to the point where flow velocity has increased due to the slope to the required velocity for scouring in a straight pipe.

At steady state there are accumulations of heavy solids at specific locations with small increases in head loss but no danger of blockage. Until redesign of the appurtenances eliminate this situation, periodic cleaning should be sufficient.

To minimize this scouring problem, it is recommended that steel and heavy metal scrap be eliminated prior to the grinding because of the excessive velocities required for satisfactory scouring of these constituents. Aluminum, glass and sandy materials are acceptable.

CHAPTER 1

INTRODUCTION

General

The population of the United States is less than 10 percent of the world's population, yet the people of the United States consume nearly half of the earth's industrial raw materials. One of the results of this disproportionate rate of consumption is the vast amount of solid waste produced. Estimates of the total solid wastes generated in this country range as high as 3.65 billion tons per year or equivalent to 100 pounds per capita per day. These values are expected to double by the year 2000. Agricultural, mineral and industrial wastes constitute almost 93 percent of this total. However, though the urban component of the solid wastes is only 7 pounds per capita per day or 256 million tons per year, its effect on the quality of human life in the congested metropolitan centers of this country is most significant. Inefficient and improper methods of collection, transportation and disposal of solid wastes result in scenic blights, and create serious hazards to public health, including pollution of air and water resources, accident hazards, and increases in the population of rodents and other carriers of disease. Though we live in a space age era, the technology associated with solid waste management is as old as the automobile.

Solid waste collection, transportation and disposal is a $5 billion a year industry of which 75 percent of the total cost can be attributed to collection and transportation. Most existing methods of urban solid waste disposal utilize trucks for collection and transport to either incinerators or city dumps for landfill operations. Except for the introduction of the modern day sanitary packer truck, there has been no significant improvement in collection and transportation methods. Curbside collection of domestic refuse from trash cans is unsightly, unhygienic and obsolete.

The average householder pays between $35 to $50 annually for collection and transportation of household refuse and this cost is constantly increasing. Labor is the most expensive component of this collection cost and is expected to rise at an increasing rate, if the present trend of labor costs continues. A viable alternative to this system which is more capital and less labor intensive, is required.

The "Trash Compactor" is presently being sold for household use. It compacts household waste into a paper bag, thus reducing its volume and producing a hygenic package of refuse.

However this method still requires curbside collection and transportation of the refuse package for ultimate disposal. There is some indication that trash in this compacted state may be difficult to incinerate. The proposed "Pneumo-Slurry" system (1) for collection and transportation of solid waste utilizes pneumatic collection and transport of household waste from individual homes or apartments to a central municipal grinding facility where it is pumped over long distances to its ultimate disposal site through pressure pipelines. The system requires a large capital investment in pipelines and a large grinding facility in order to make it operational.

The present trend in solid waste disposal is towards conservation, reuse or resource recovery, as land fill sites close to metropolitan areas become harder and more expensive to come by and stricter air pollution controls are placed on incineration. Most reuse systems require the waste in a shredded or ground state. The concept of grinding the refuse at the household and transporting it hydraulically through existing sewer lines is a possibly attractive alternative to the present collection and transportation schemes or any other systems presently being proposed. It eliminates the high labor costs associated with conventional pick up, without requiring any excessively high capital investments for the transportation system as it uses the existing sewer network. It also presents the refuse in a ground state at a central treating facility where it could be suitably processed for ultimate disposal or reuse.

The feasibility of this concept depends on demonstrating first, that the ground refuse can be hydraulically transported through existing sewers without overloading them; second, that the refuse can be separated and treated at a treatment plant; and third, that a household refuse grinder can be designed, built and operated at a cost which is competitive with the cost of normal refuse collection and transportation.

A program to demonstrate the feasibility of this concept of grinding and transporting household refuse through existing sewer lines was undertaken by Foster-Miller Associates under Contract CPE-70-115 to the Bureau of Solid Waste Management, Environmental Control Administration, Department of Health, Education and Welfare, Cincinnati, Ohio.* Phase I (2) was directed at evaluating the feasibility of hydraulically transporting and treating ground household refuse and Phase II (3) was concerned with the preliminary design of a household refuse grinder.

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* Environmental Protection Agency, Office of Research and Monitoring, National Environmental Research Laboratory, Cincinnati, Ohio, Solid Waste Research Laboratory.

The results of Phase I demonstrated, on a limited scale, the technical feasibility of hydraulically transporting ground refuse slurries through the straight sections of sewer pipes. The program, covered by this report, represents an experimental investigation of the flow of ground refuse slurry through siphons, bends and sewer appurtenances; critical elements in any standard sewer system. Establishing the flow characteristics through these critical elements was considered to be essential in demonstrating the feasibility of the ground refuse slurry sewer transport system. In order to provide the reader with the necessary background for the more detailed investigations reported in this document, a summary of the results of Phase I of the previous program (2) is presented in the following section.

Summary of Previous Investigation

The objectives of this program were twofold. First, to establish the feasibility of hydraulic transport of ground household refuse through sewers by studying the gravity flow of ground refuse slurry through inclined pipes. In particular, to determine the maximum solids contents and average particle size of ground refuse that can be transported through existing sewers without altering their grades. Second, to conduct a preliminary evaluation of the feasibility of treating domestic sewage containing ground refuse through a laboratory analysis of the sewage-refuse slurry. The effectivness of existing sewage treatment processes on the sewage-refuse slurry will be evaluated. The results of these studies will be utilized to determine the specifications of a household refuse grinder.

These program objectives were achieved by Foster-Miller Associates, with Metcalf and Eddy, Inc., Boston, acting as principal subcontractor for that phase of the study which dealt with the feasibility of treating domestic sewage containing ground refuse.

The results of this study have shown that the concept of hydraulically transporting ground household refuse and treating it at a sewage treatment plant appears to be feasible. Much further work needs to be done before an actual system utilizing this concept can be demonstrated. Recommendations for further research areas have been made.

Hydraulic Transport of Ground Refuse Through Sewers. The hydraulic flow, under gravity, of ground refuse slurry through inclined sewer pipes was measured in an experimental test loop set up in our laboratories. Tests were conducted to measure the effects of pipe roughness, refuse type, refuse concentration and flow rate. Glass, Transite and corrugated aluminum sewer pipes were tested. A variety of different types of ground refuse was simulated by grinding synthetic

and domestic refuse through a hammermill, a Wascon hydropulper, and a Wascon hydropulper Dorr-Oliver Gorator combination.

The study showed that based on the average solid waste generation rates and average water consumption rate, the average refuse concentration in the slurry is estimated to be 0.5 percent. The friction head loss for the flow of ground refuse slurry through smooth pipes, such as glass and Transite, and rough corrugated aluminum pipes is equal to or, less than that with clear water. Sewers normally flowing half-full with water can transport a maximum refuse concentration of 1 percent through smooth pipes and 0.8 percent through rough pipes, without experiencing any change in flow behavior. With the sewer flowing full, the refuse concentration limit can be as high as 1.5 percent before any overloading of the sewer capacity will occur. These limiting concentration values are reasonably above the average concentration anticipated in the sewer line. Thus it can be concluded that the 0.5 percent ground refuse slurry will flow in a manner similar to clear water and that the transport of such slurries through existing sewers should be technically feasible.

At higher concentrations, approaching 2 percent, the friction head loss increases over that of water, thus causing a reduction in the sewer capacity. At 2 percent concentration, the capacity of a sewer flowing full is reduced to 60 percent of its design capacity with water.

Over the range of conditions tested, the heavy glass and metal particles settled to the bottom and were transported by sliding along the bottom surface. At velocities above 1.5 ft/sec and refuse concentrations less than 1.5 percent the lighter refuse constituents, such as, paper, plastics, cloth, etc., were transported as a heterogeneous suspension without settling. At velocities less than 0.8 ft/sec, a sliding bed type of flow was observed with settling of the light constituents to form the bed. At these low velocities, the possibility of obstructions in the flow path leading to solids build-up and clogging is high. At high refuse concentrations of greater than 2 percent and velocities up to 4 ft/sec a plug type flow occurs, where all the solids move en masse without relative motion and settling. Even heavy glass and metal pieces can be carried in suspension at these concentrations.

At the dilute concentrations of less than 1.5 percent a minimum velocity of 2.5 ft/sec is essential to scour the heavy deposits of glass and metal and maintain self cleaning conditions. At the higher concentrations, of greater than 2 percent, the particles are carried in suspension and no minimum velocity is required.

As the normal design flow velocity in sewers is generally greater than 2.5 ft/sec, the ground glass and metal pieces

should be transportable through the straight sections of most sewers. It is likely that some deposits may form during periods of low flow. However, scouring of these deposits at periods of normal flow should be sufficient to maintain the straight sections reasonably clean.

The type of grinding operation, be it dry, such as the hammermill or wet, such as, the hydropulper, has no effect on the refuse slurry flow for particles less than 1.5 inches in size, over the range of refuse concentrations and flow velocities investigated.

Of all the constituents of household refuse, cloth and rags were the most troublesome. Both dry and wet grinding reduced cloth to long stringy pieces which tend to wrap around any obstruction in the flow path and lead to clogging. Cloth should be ground into small rectangular pieces of 1.5 inches maximum size before introducing it into the flow or it should be excluded.

Finally, the experimental data was analyzed using the variable Manning constant representation for open flow through circular pipes to include the effect of refuse concentration. Design charts were drawn up for the various hydraulic elements based on the full flow conditions with clear water. These charts can be used by the designer to either design sewers specifically to transport ground refuse or to evaluate the performance of existing sewers when transporting refuse.

Treatment of Domestic Sewage Containing Ground Refuse. A laboratory investigation was conducted in order to evaluate the preliminary feasibility of treating ground household refuse with domestic sewage. Household refuse from Cincinnati, raw sewage from Boston, and activated sludge from the Brockton sewage treatment plant were prime constituents of many of the samples prepared. Tests were conducted to determine total solids, total volatile solids, suspended solids, settleable solids, biological oxygen demand, chemical oxygen demand, oxygen uptake, pH, total kjedahl nitrogen, total phosphorous, total chlorides and grit.

The study showed that it is possible to dispose of the solid wastes by the proposed method. At 0.5 percent, by weight, ground refuse in sewage, the BOD (biochemical oxygen demand) in the supernatant of settled wastewater was increased 1.5 times and the COD (chemical oxygen demand) 2.3 times above those values for settled sewage alone. The TS (total solids) and TVS (total volatile solids) in the supernatant of settled ground refuse in sewage were slightly more while the SS (suspended solids) and VSS (volatile suspended solids) were slightly less. Other parameters not affected or only slightly affected were chlorides and metals. Nitrogen and phosphorus were present in sufficient quantity for biological treatment.

Mechanical means of reducing the moisture content of the primary sludge presently exist and several were tested. Dewatered sludge with a solids content as high as 30 percent was obtained.

A treatment plant to handle ground refuse in sewage would have much of the same equipment as a "normal" treatment plant; however, the sizing of certain units, such as aeration tanks, and vacuum filters, would have to be increased. Certain parts of other units, such as impellers in sludge pumps and skimming mechanisms in clarifiers may have to be altered or strengthened. These are very preliminary conclusions based on a limited laboratory investigation. Much further work needs to be done in this area.

No method for final disposal was attempted in our laboratory, but it was believed that the dewatered sludge would be amenable to disposal via several methods such as incineration and composting.

The major problem remaining was the amount of sludge produced. A study by the Los Angeles County Sanitation Districts showed that the primary sludge volume could be increased by as much as 25 times.

Very preliminary cost analyses for three sewage treatment plants were developed, one for the treatment of domestic sewage with the characteristics of Boston sewage, and the others for the treatment of ground refuse with domestic sewage. Each plant was sized for one million gallons per day capacity. Order of magnitude estimates indicate that the capital cost of a treatment plant to handle the ground refuse with domestic sewage would be 2.5 to 4.5 times the cost of sewage treatment alone. This cost does not include the cost of final disposal.

The level of effort devoted to this area of investigation was extremely limited and consisted of a laboratory investigation only. Thus, the conclusions are quite preliminary in nature. Much further work needs to be done on the treatment of sewage containing ground domestic refuse. A recommended program for future investigation is included in the Phase I report (2).

Objective

The objective of the program discussed in this report is to extend the feasibility study of hydraulic transport of ground refuse in sanitary sewers of conventional design. This study is designed to demonstrate the feasibility of ground refuse flow through bends, stilling basins, overflow weirs, inverted siphons, lift stations and similar appurtenances encountered in normal sewer design practice.

Key factors to be considered in evaluating the feasibility are:

(a) The minimum flow rate at which a refuse slurry can be satisfactorily transported through the pipe system and its appurtenances.

(b) The rates, types and classes of material deposited or expected to be deposited in the pipe system and its appurtenances.

(c) Modifications in the design of the appurtenances necessary to minimize deposition of material or other conditions leading to unsatisfactory flow.

Scope of Program

The scope of the program included an experimental investigation of the gravity flow of ground household refuse through a wide range of sewer appurtenances. These included inverted siphons, running traps, bends, manholes, pump well inlets, lift stations and obstacles. The investigation was conducted in a hydraulic test loop set up in the Foster-Miller laboratory.

The subsequent chapters of this report summarize the results obtained during the course of this program. A descritpion of the experimental program including the test facility, the test procedure and the range of parameters tested is presented in Chapter 2.

CHAPTER 2

EXPERIMENTAL PROGRAM TO STUDY FLOW CHARACTERISTICS OF GROUND REFUSE SLURRY

Objective and Scope of Experimental Program

This investigation was undertaken to demonstrate the feasibility of transporting ground refuse through the appurtenances commonly found in sanitary sewers of conventional design. The appurtenances of interest include bends, overflow weirs, stilling basins, inverted siphons, lift stations, manholes, junctions and size transitions.

The effort included extensive modification and expansion of an existing flow facility to permit the evaluation of a wide range of flows through the appurtenances listed above. The details of the modifications required for each appurtenance tested will be presented in the chapter in which that appurtenance is discussed.

The test program employed domestic refuse ground in a Wascon Hydropulper and dewatered in a filter press.

The refuse was added in various concentrations to determine:

(a) The minimum flow rate at which the refuse slurry can be satisfactorily transported through the sewer system and its appurtenances.

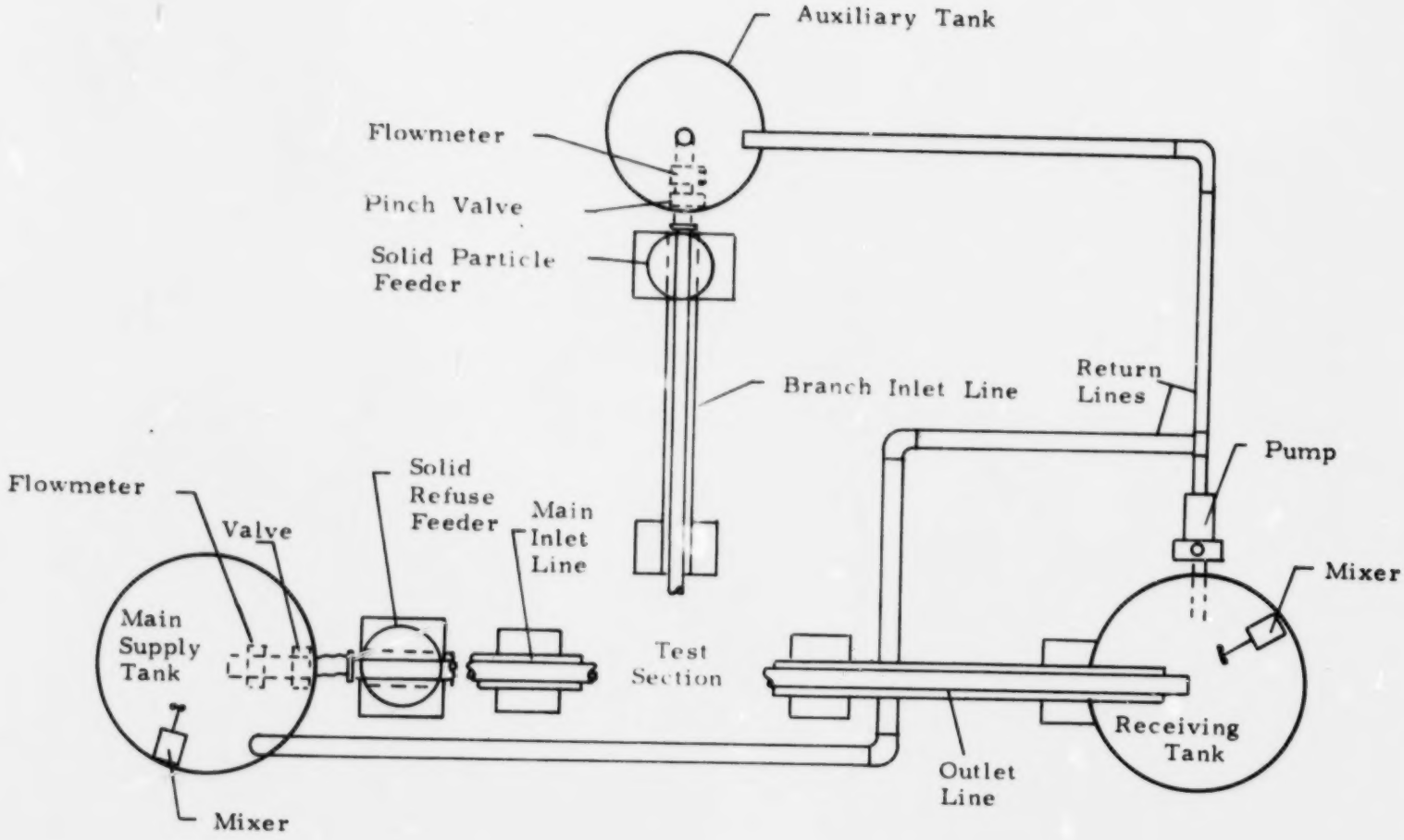
(b) The types or classes of materials deposited or expected to be deposited in the pipe system and its appurtenances.

(c) Modifications in the design of the appurtenances necessary to minimize deposition of material or other conditions leading to unsatisfactory flow.

Hydraulic Test Facility

The basic hydraulic test facility is presented in Figure 1. It consists of three large steel tanks of approximately 1500 gallon capacity. Two of these tanks are elevated approximately eight feet above the floor level to provide the head required to produce the flows. An ITT Marlow Vane-Flo centrifugal pump with 350 gpm capacity transfers the slurry from the lower tank to either or both of the upper tanks. Each tank is equipped with a 1 HP Chemineer mixer to insure uniformity of the mixture in each tank.

The slurry flows from either or both of the upper tanks to the lower tank through a system of glass pipes through which the



Schematic Diagram Hydraulic Test Facility

Figure 1

flow may be observed and recorded. These pipes are supported on a triangular truss section in such a manner as to facilitate rapid changes in pipe size, pipe slope or appurtenance configuration. 6" diameter glass pipe was used for the main line and 4" diameter glass pipe for the branch line as shown in Figure 1.

In the center of this pipe a test section was included where each of the appurtenances to be tested was installed. By careful design of this test section it was possible to install either bends, manholes, siphons, tees or running traps with a minimum of modification. A minimum of 15 feet of straight pipe (L/D = 30) upstream of the test section permitted stabilization of the flow pattern prior to entry in the test section. Slopes of the inlet and outlet pipes were independently adjustable over a wide range. The slope of the test section was also adjustable.

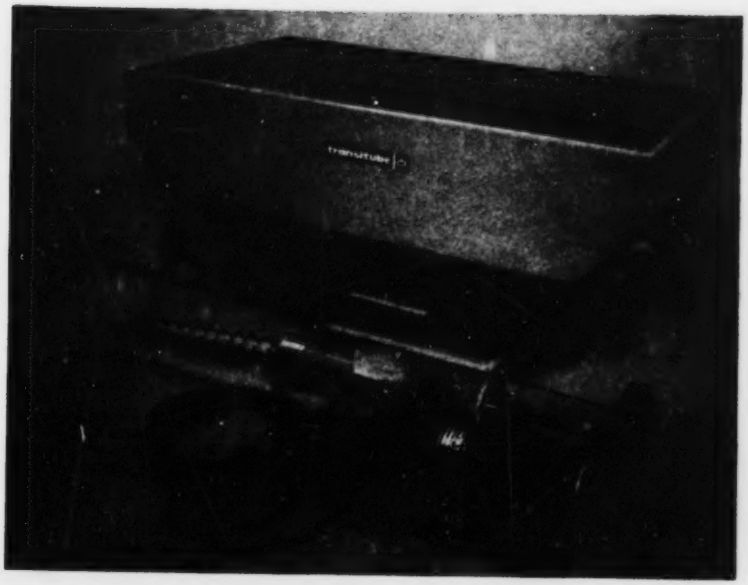
Two Fischer & Porter magnetic flow meters were used to monitor the flow rate from the upper tanks. A solids feeder metered heavy solids such as steel chips, glass, aluminum and sand, into the flow at predetermined rates to eliminate the uncertainty inherent in recirculating solids which tend to settle out. This is shown in Figure 2. It operates like a screw conveyor in which the feed rate can be varied by varying the rotational speed. Several of the tests required special instrumentation or equipment as discussed in detail in the appropriate section.

Characteristics of Domestic Refuse and Heavy Solids

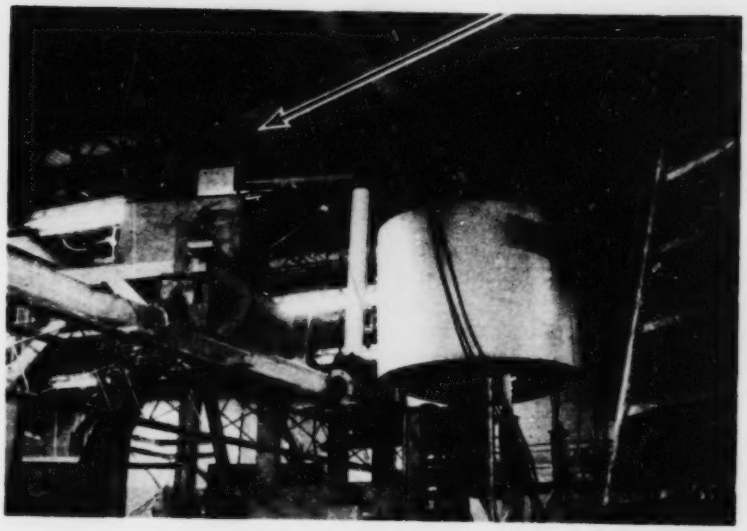
The hydraulic tests of Phase I were principally conducted with ground refuse produced in a Wascon hydropulper located in the Currier dormitory of Radcliffe College, Cambridge, Mass. This refuse consisted of all the household waste generated in the dormitory, but excluded metal cans and heavy metal objects. The results of Phase I have shown that for the particle size of interest, (i.e. less than 1 inch) the type of grinding operation has no effect on the flow characteristics of the ground refuse slurry. Consequently, the experimental investigations of this program were conducted with ground refuse obtained from the Wascon hydropulper located at the Radcliffe dormitory.

To compensate for the absence of heavy solids, such as metal and glass in the Radcliffe ground refuse, heavy solids of several types were added into the flow system for the scouring tests. The solids feeder, shown in Figure 2, was used for this purpose.

The solids included steel chips, ground glass, sand and heavy solids ground by EPA. The characteristics of each type are presented in Table I.



(a) Feeder and Controller Assembly



(b) Installed in Test Loop

Heavy Solids Feeder

Figure 2

TABLE I

CHARACTERISTICS OF HEAVY SOLIDS
USED IN TEST PROGRAM

Solid	Bulk Specific Gravity	Maximum Size of Particle	Description
EPA Ground Refuse	1.28	1/4"	Ground by Hammermill at EPA to get 1/4" size; Natural solid refuse
Ground Glass	1.46	1/8"	Canada Dry Bottles ground at FMA
Ottawa Sand	1.49	0.04"	Uniform, smooth sand
Steel Chips	4.33	1/16" thick pellet	Circular Plugs

Types of Tests and Procedures

In general, the test program for each appurtenance consisted of two major parts:

(1) Determining the head loss through the appurtenance as a function of refuse concentration.

(2) Determining the minimum velocity required to satisfactorily scour typical heavy solids deposited in each appurtenance.

Tests to Determine the Head Loss of Ground Refuse Slurry Through Appurtenances. The flow of ground refuse slurry through appurtenances was characterized in terms of its head loss as a function of refuse concentration. Tests were conducted with clear water and with varying ground refuse concentrations up to 1.5 percent maximum.

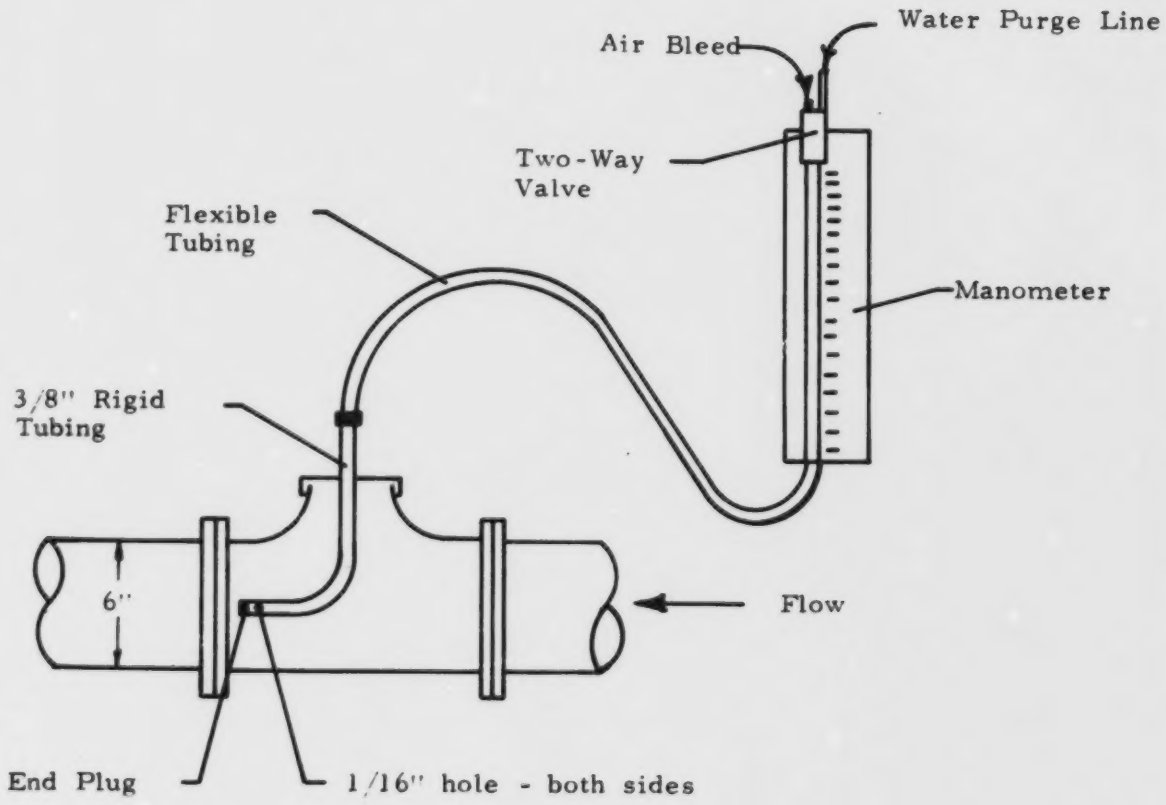
The head loss for open channel flow conditions was determined by measuring the depth of flow at the test points and the gradient of the test section between the test points. For full flow situations, manometers were used to measure the static pressure at specific locations in the flow. These static pressure taps were designed, as shown in Figure 3 and installed through tee-sections of the glass pipe. The manometers were continuously flushed with water to prevent clogging. When taking a reading, the flushing water was shut off and the manometer vented to the atmosphere through a two-way valve.

Scouring Velocity Tests. The heavy solids fraction of the ground refuse will settle to the bottom of the sewer pipe and be transported either by saltation or as a sliding bed. Below a critical flow velocity, the heavy solids accumulate at the bottom of the pipe. As the flow velocity is increased scouring begins with saltation. Particles are picked up at the upstream end of the pile, rolled across the pile and redeposited at the downstream end of the pile. The pile moves slowly down the pipe as if by rolling. As the flow velocity is increased further the entire pile begins to slide down the pipe at a velocity considerably less than the flow velocity. This is referred to as a sliding bed type of flow.

For our test purposes we have defined two scouring velocities:

(1) Initial scouring velocity which is the minimum velocity required to clean solids by saltation as they are added at a specific rate. A steady state layer of solids may remain.

(2) Clean out velocity which is the minimum velocity required to totally remove all solids from the pipe bottom including existing accumulations of previously deposited solids. The pipe is totally clear of all solids.



Static Pressure Tap and Manometer Installation

Figure 3

In some cases these velocities are almost identical whereas for others they differ markedly. These velocities depend on particle size, material feeding rate and the refuse concentration in the transporting flow. The most critical situation occurs with clear water. Consequently most of the scouring velocity tests were conducted with clear water. This also aided flow visualization.

A wide range of heavy solids were tested during the program. The characteristics of the various types are presented in Table I. The feeding rates were selected to simulate appropriate heavy solids loadings based on typical concentrations of domestic refuse. The typical heavy solids concentrations in domestic refuse are presented in Table II. Based on this, a typical test condition of 350 gallons per minute of flow at a 1 percent refuse concentration containing a heavy solids content of 21 percent would require a heavy solids feed rate of 6.1 lbs per minute.

Range of Test Parameters

Types of Appurtenances. The following different sewer appurtenances were tested:

(1) inverted siphons - 22-1/2°, 45°, 60° - all 6" diameter

(2) running trap - 6" diameter

(3) bends - 45°, 60°, 90° - 6" diameter

(4) manholes 4" - 6" size transition;
slope transition - 6" diameter;
90° bend - 6" diameter

(5) junction flows - 6" - 4" - 6" tee

(6) pump inlet - 4" diameter

(7) stilling basin

(8) overflow weirs

(9) obstacles

Details of the description and size of the appurtenances are to be found in the relevant chapters describing the test evaluation.

Refuse Concentration. The concentration of ground refuse slurry ranged from 0 to 1.5 percent. The ground refuse was obtained from the Currier dormitory of Radcliffe College, Cambridge, Mass. and was ground in the same Wascon hydropulper used during the Phase I study. (2)

TABLE II

TYPICAL HEAVY SOLID CONTENT OF HOUSEHOLD REFUSE

Solid Type	Percent by Weight in Total Refuse
Glass	11
Metal	7.5
Sand and Ash	2.5
Total	21 percent

Flow Rates. The slurry flow rate ranged from almost zero to 350 gallons per minute.

CHAPTER 3

INVERTED SIPHON EVALUATION

A siphon in sewerage practice almost invariably refers to an inverted siphon or depressed sewer which would stand full even with no flow. Its purpose is to carry the flow under an obstruction such as a stream or depressed highway and to regain as much elevation as possible after the structure has been passed.

It is common practice to construct multiple-barrel siphons to provide adequate self-cleaning velocities under widely varying flow conditions. The primary barrel is designed so that a velocity of 2 to 3 ft/sec is reached at least once per day. Additional pipes regulated by lateral overflow weirs assist progressively in carrying flows of greater magnitude.

The profile of the siphon has been designed to provide easy cleaning at a minimum hydraulic loss. A commonly used siphon system for shallow passage is shown in Figure 4 and for deep passage using a vertical pipe system in Figure 5.

The major problem areas needing investigation are:

(1) The effect of refuse concentration on the head loss through the siphon including elbows and inclined pipes.

(2) The minimum self-cleaning velocity required for flow through elbows and up inclined pipes.

(3) The effect of solid deposition during no flow.

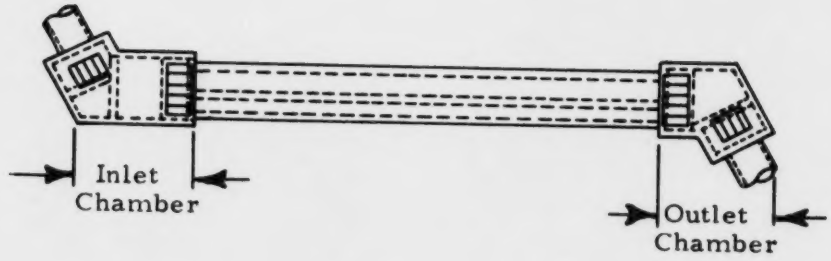
The laboratory program described in the following sections was designed to investigate these areas.

Experimental Facility and Test Procedures

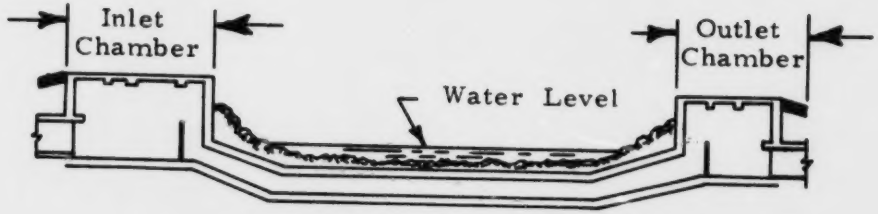
A schematic diagram of the siphon flow facility is presented in Figure 6 with photographs in Figures 7 and 8 showing the 45° and 60° siphons. A 22-1/2° siphon was tested in addition. All three siphon configurations used 6" glass pipe. The horizontal run was 10' with the sloping legs 5' in length.

To ensure that full flow was maintained over a wide range of flow rates the outlet was submerged in a large drum, as shown in Figure 9. The discharge height was varied appropriately with varying flow rate to maintain full flow conditions. This method worked very satisfactorily even at very low flow rates.

Under these full flow conditions, head loss was measured with pressure taps and manometers of the type shown in Figure 3. Static pressure was measured at the inlet and outlet to the siphon as shown in Figure 6.



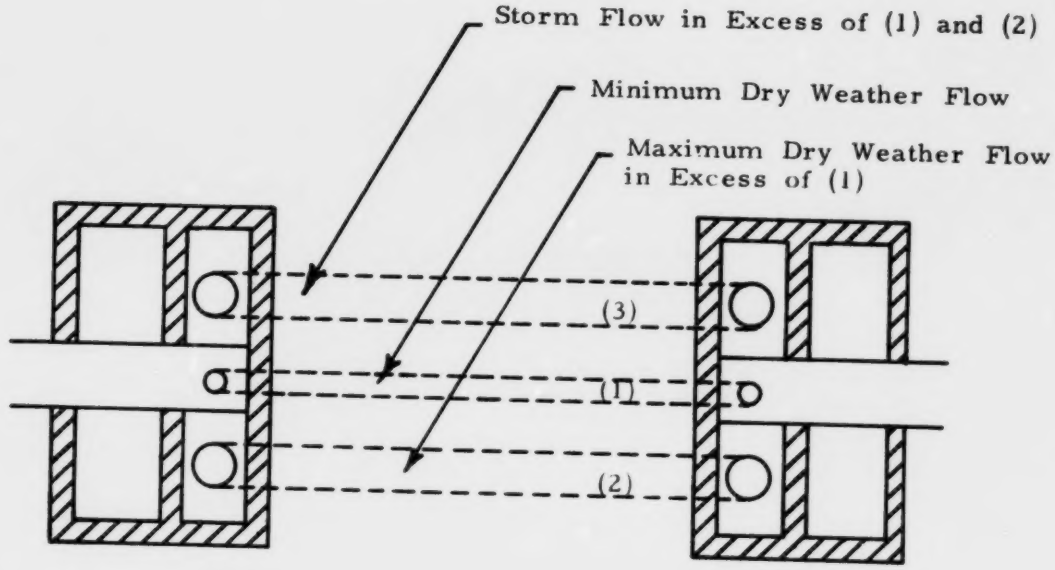
(a) Plan View



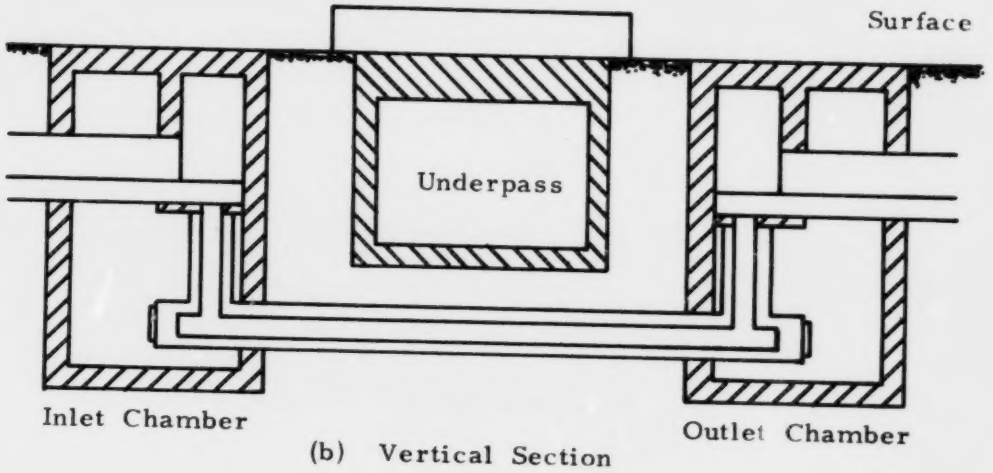
(b) Profile

Typical Twin Barrel Siphon System

Figure 4



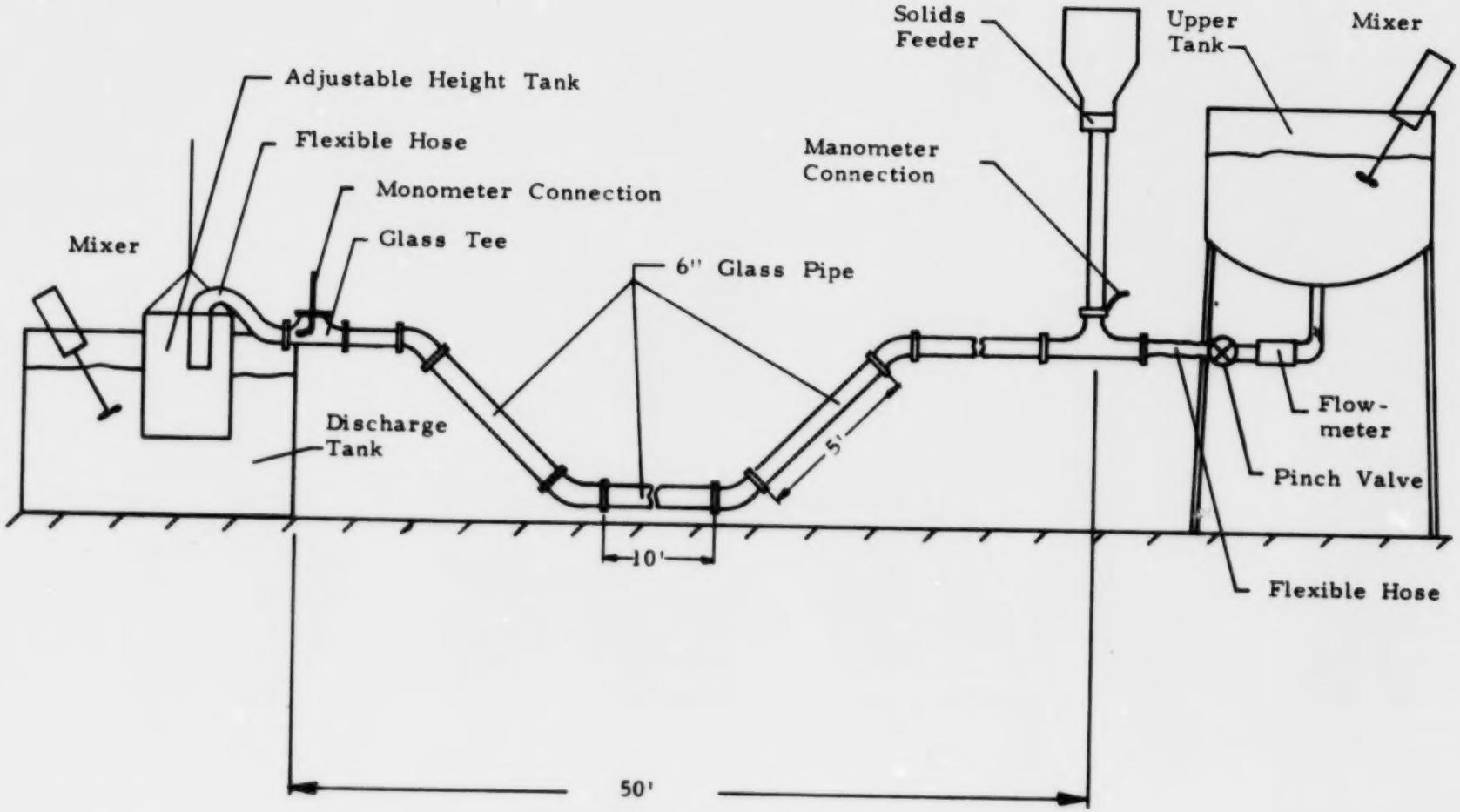
(a) Plan View



(b) Vertical Section

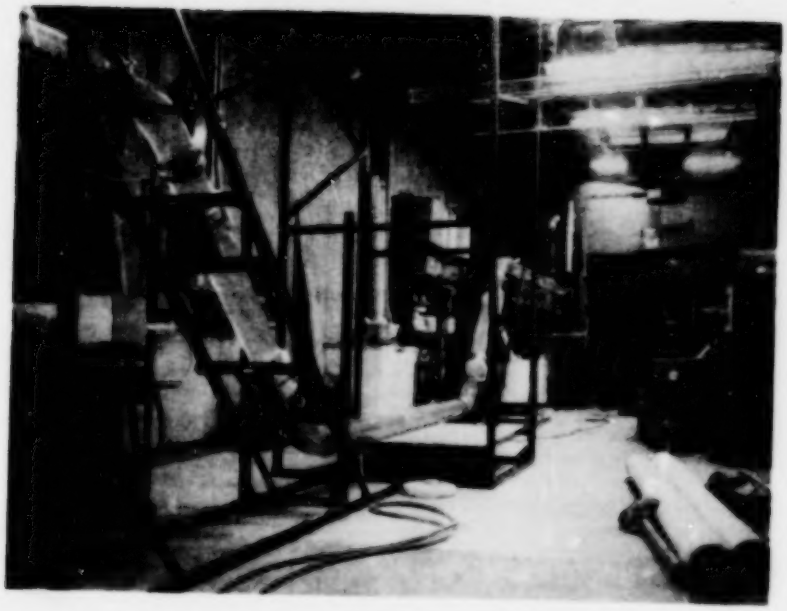
Inverted Siphon for Combined Sewage Flow

Figure 5

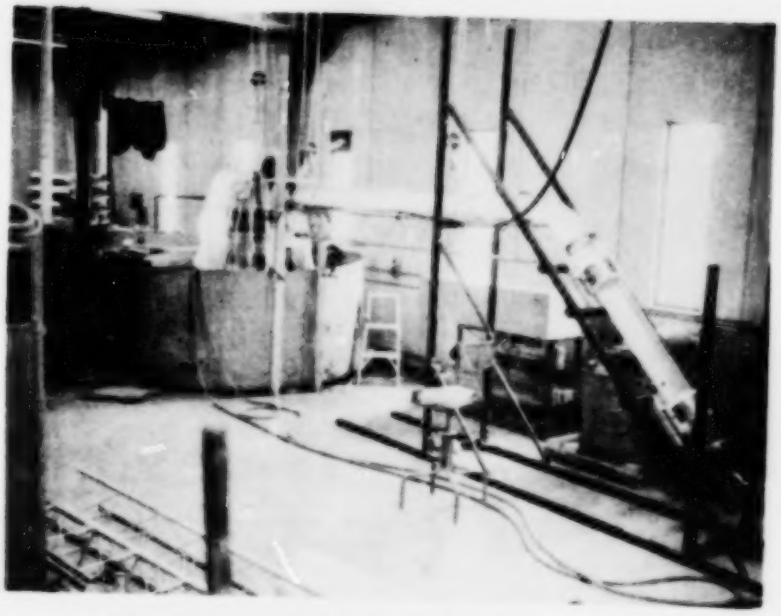


Inverted Siphon Test Loop

Figure 6



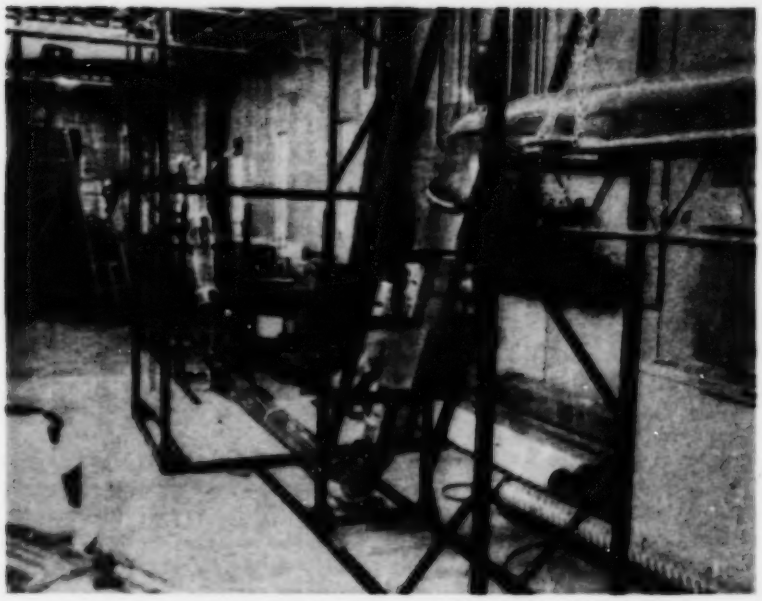
(a) Siphon and Upper Tank



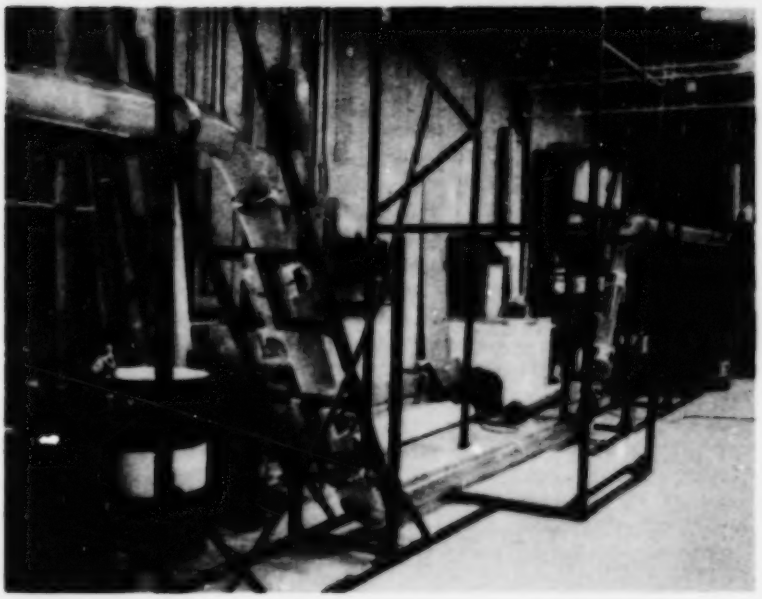
(b) Lower End and Discharge Tank

45° Inverted Siphon Test Facility

Figure 7



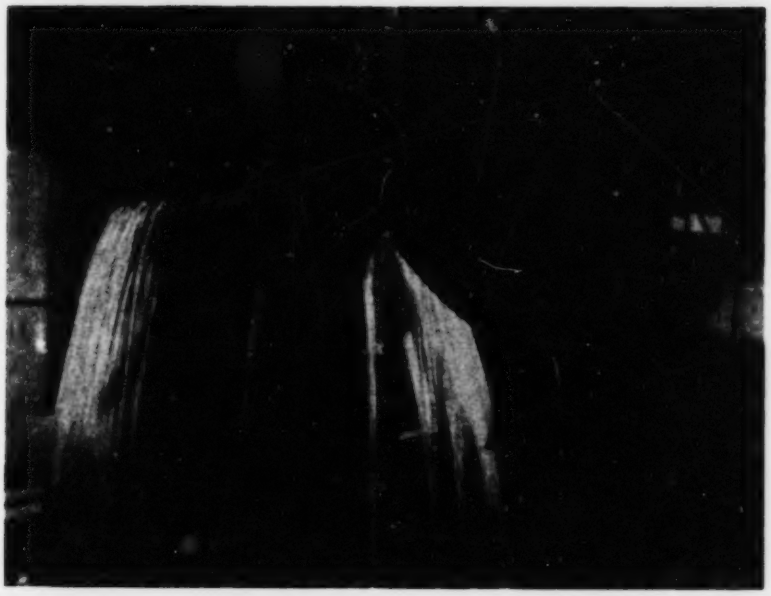
(a) Facing Downstream



(b) Facing Upstream

60° Inverted Siphon Test Facility

Figure 8



Submerged Siphon Discharge

Figure 9

For each inverted siphon configuration, the head loss was measured as a function of flow rate for refuse concentrations of 0.0, 0.5, 1.0 and 1.5 percent.

To determine the initial scouring velocity the solids feeder was operated at a fixed rate and the water flow slowly increased. The minimum velocity at which the heavy solids cleared continuously without any accumulation was recorded as the initial scouring velocity.

The clean out velocity was determined by placing a large pile of heavy solids in the pipe as shown in Figure 10 and then increasing the water flow until the pile dispersed and slid downstream.

The scouring velocity tests were run primarily with clear water. The data was rechecked with 1.0 percent refuse to ensure that the measured scouring velocities were essentially independent of the suspended refuse content in the main flow.

Experimental Head Loss Results

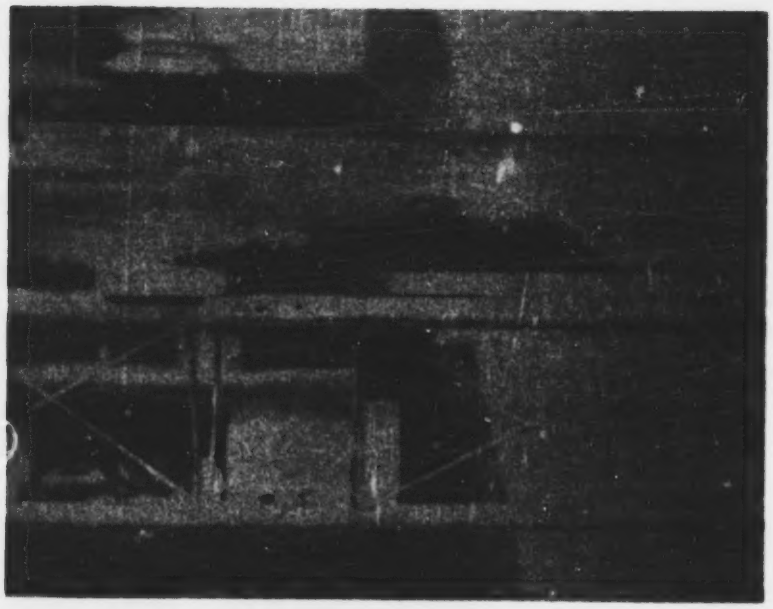
The measured variation of head loss with flow rate and refuse concentration is shown in Figures 11, 12 and 13 for the 22 1/2°, 45° and 60° siphon systems respectively. Figures 14 and 15 compare the head loss of the siphon systems with an equal length of straight pipe for clear water and 1.1 percent refuse slurry respectively. The higher head loss of the siphon systems is attributed to the extra head loss occurring in the four elbows. The salient results obtained from this experimental investigation are summarized as follows:

(1) The general flow behavior of the ground refuse slurry through the siphons is similar to that observed in the flow through straight pipes described in Reference 2.

(2) At a refuse concentration of 0.5 percent the head loss is generally less than with clear water.

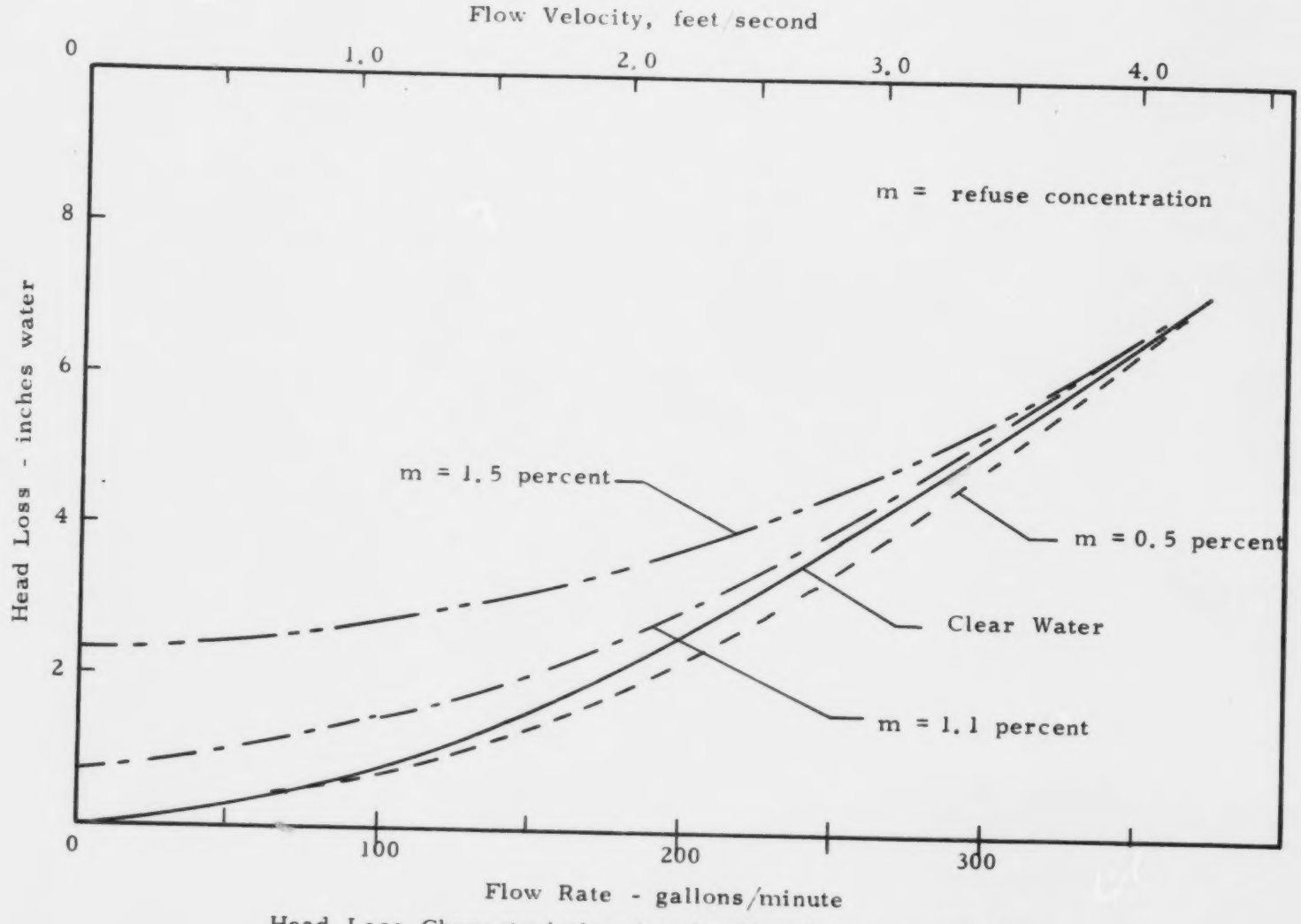
(3) At a refuse concentration of 1 percent, the head loss is essentially the same as with clear water for flow velocities greater than 2 feet per second. At lower flow velocities, much below 1 feet per second, the head loss is seen to be almost double that with clear water.

(4) At the higher concentration of 1.5 percent the head loss is always higher than with clear water, except for the 60° siphon system, where it becomes less for the higher velocities. At velocities lower than 1 foot per second, the head loss is almost three to four times the clear water loss. However, at velocities greater than 3 feet per second this increase becomes insignificantly small and the curves merge with the clear water loss curve.



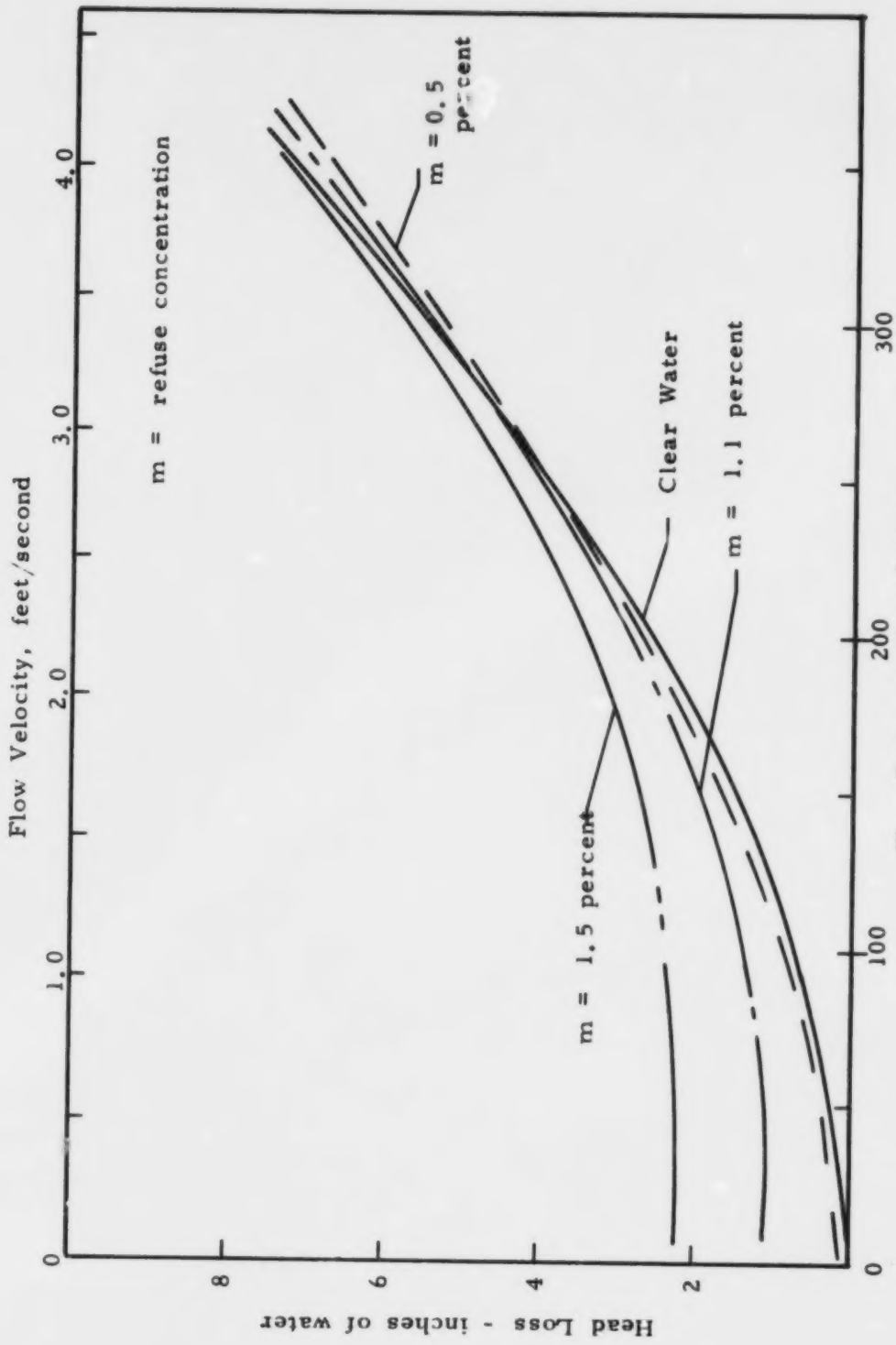
Heavy Solids Accumulation for Scouring Characteristics Determination

Figure 10



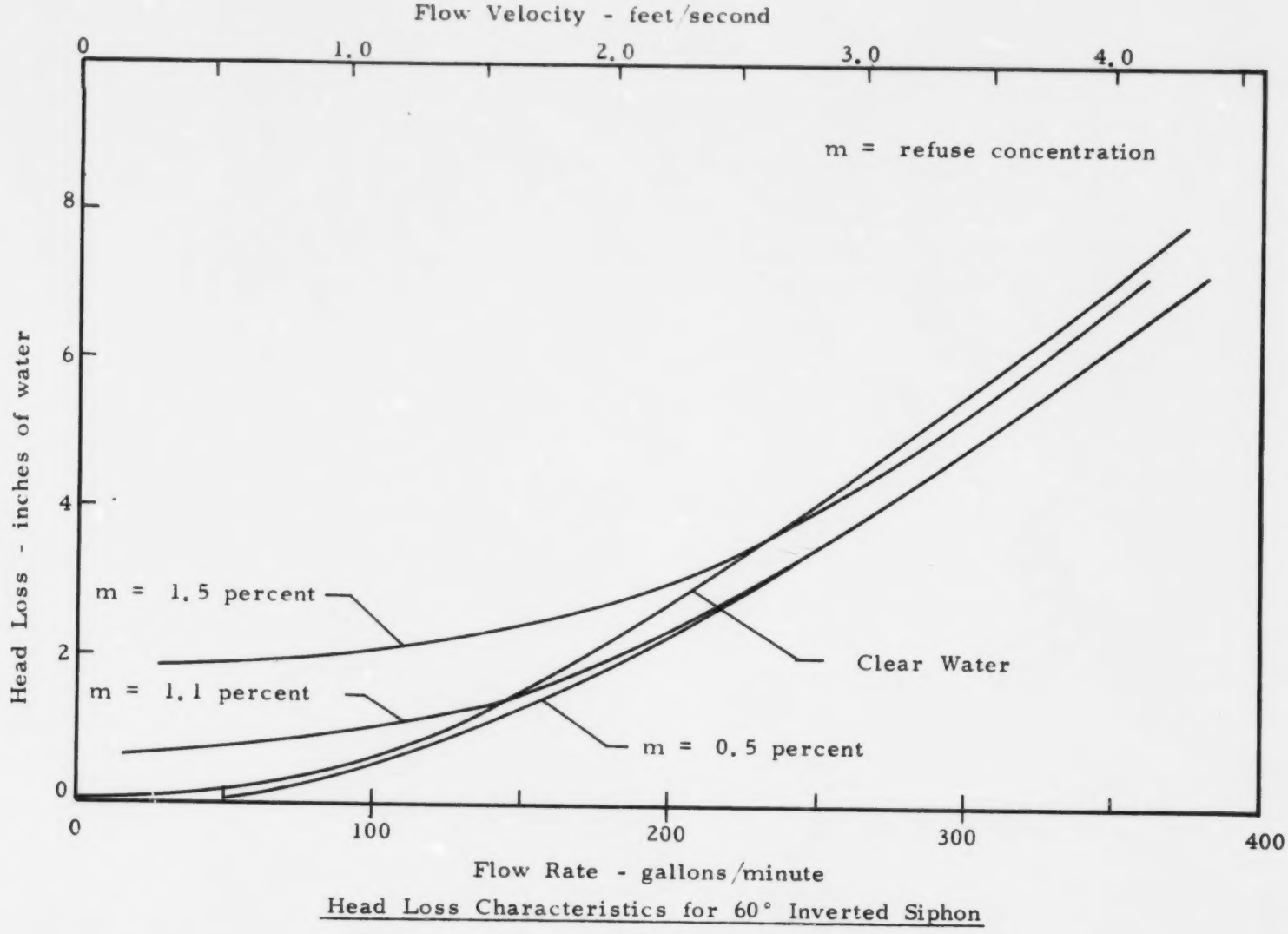
Head Loss Characteristics for the 22 1/2° Inverted Siphon

Figure 11



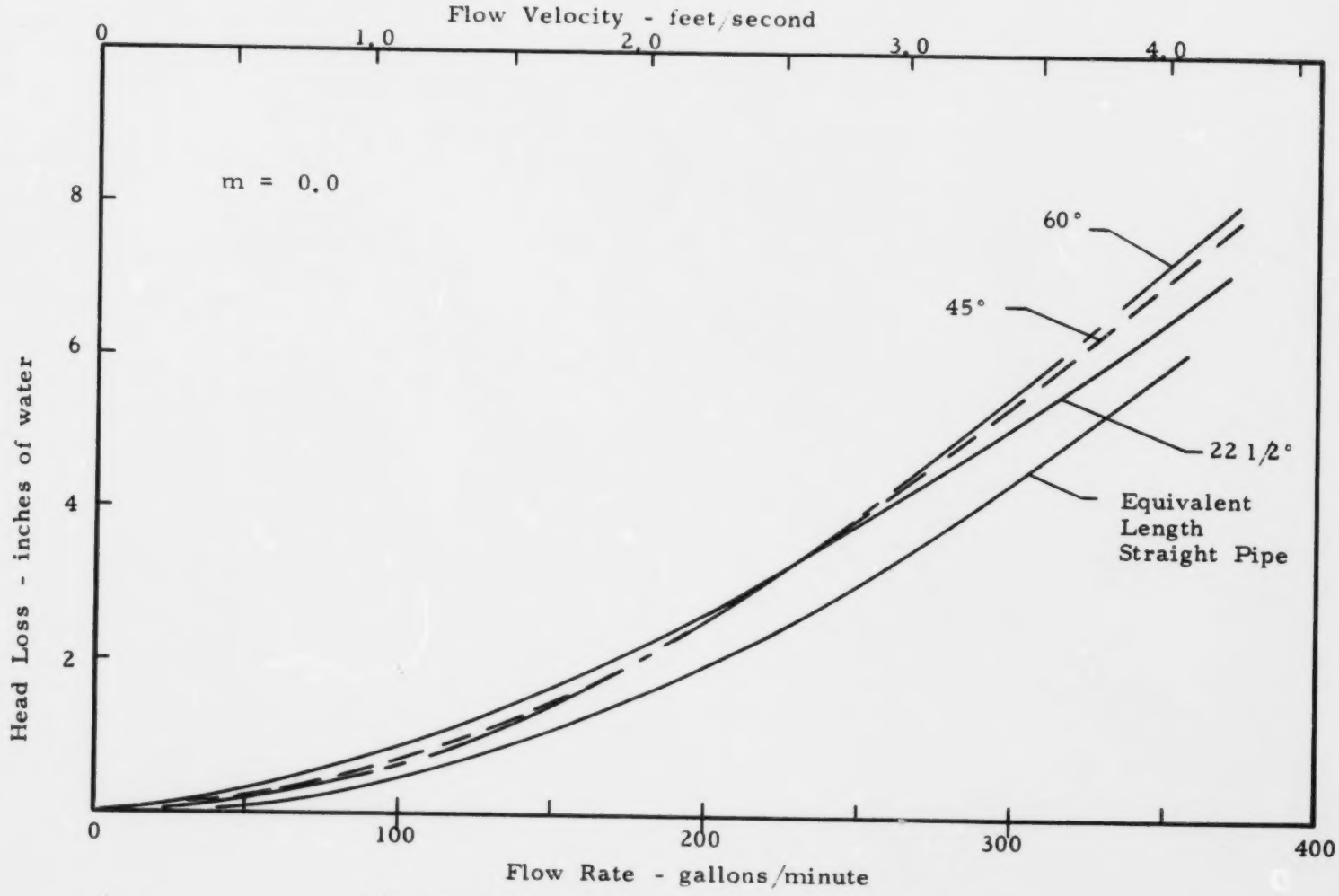
Head Loss Characteristics for 45° Inverted Siphon

Figure 12



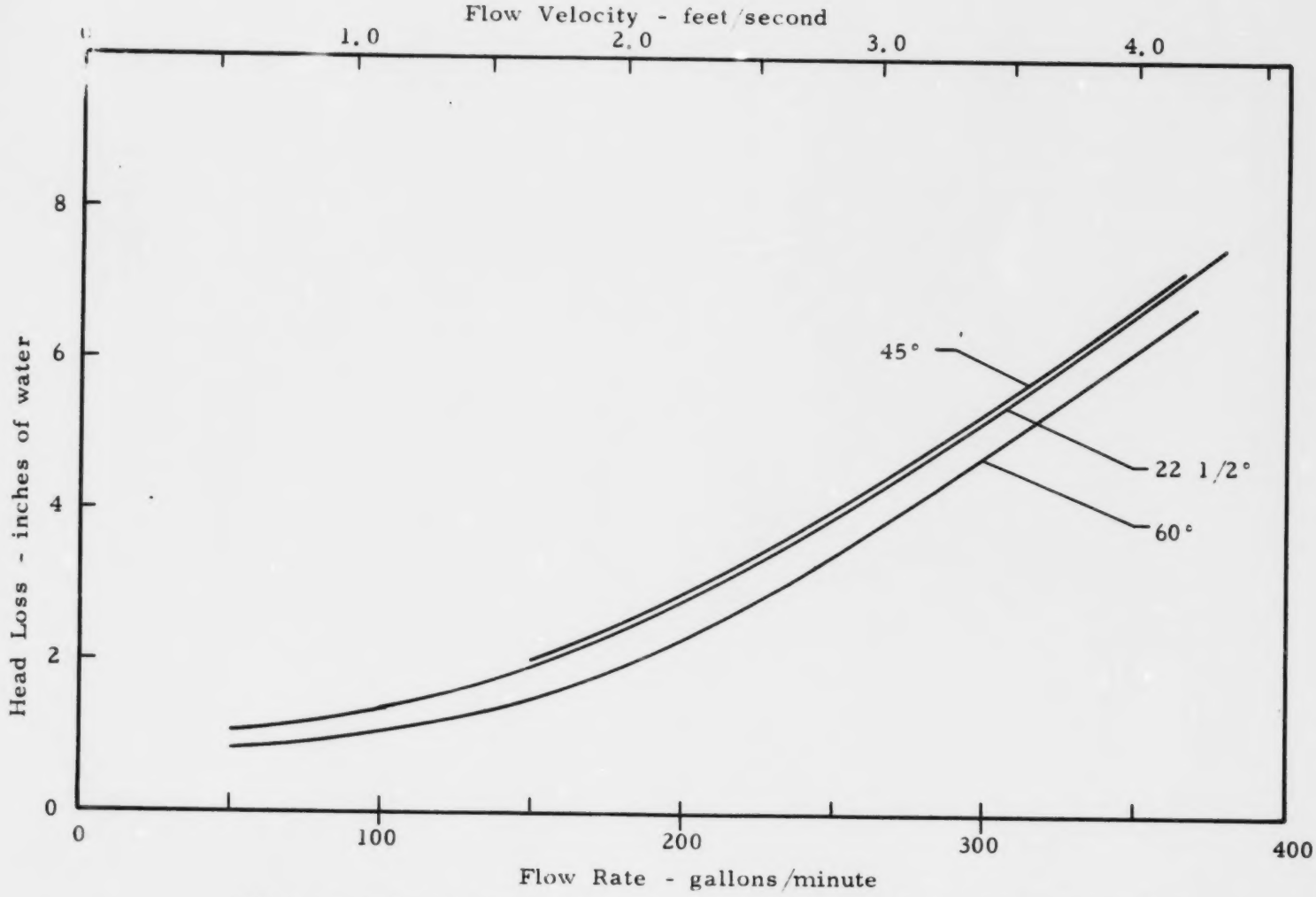
Head Loss Characteristics for 60° Inverted Siphon

Figure 13



Effect of Siphon Angle on Head Loss - Clear Water

Figure 14



Effect of Siphon Angle on Head Loss - 1.1 Percent Refuse Concentration

Figure 15

(5) The head loss variation of the ground refuse slurry is not affected by the siphon angle over the range of refuse concentrations tested. Figure 15 shows the effect of siphon angle on head loss for a 1.1 percent refuse slurry. The 60° siphon behaves differently at the high velocities, however this anamoly can be ascribed more to experimental error than to a fundamental change in performance.

Experimental Scouring Velocity Results

Through most of the elements of the siphon system the heavy solids are transported by saltation as described in Chapter 2. However, in the third elbow and the uphill leg of the siphon system, as shown in Figure 6, the flow behavior is different. In the velocity range where saltation normally occurs, a stationary rolling action occurs instead. The solids are picked up and moved uphill by the fluid only to slide back down by gravity. At a higher velocity, the fluid drag force is sufficient to overcome the gravity force and the heavy solids are transported as a sliding bed rather than by saltation. At the elbow the initiation of this sliding bed flow is followed almost immediately by complete clearing of the system.

The scouring velocity at the elbow was observed to be significantly higher than in a straight pipe. Accordingly, a parametric study was conducted to study the effect of heavy solid properties, particle size, heavy solid concentration, refuse slurry concentration and siphon angle on scouring velocity.

Table III summarizes the results for a 6-inch diameter, 45° siphon system and Table IV presents test results showing the effect of siphon angle. The latter test series was conducted with heavy solids ground in the EPA's hammermill. The significant results of this test series are summarized below.

Straight Pipe. Initial scouring and clean out velocities for materials such as glass and sand lie in the range of 1 to 2.3 fps and 2.3 to 2.7 fps respectively. However, for steel pieces comprising the metal chip and EPA solids these velocities have to be increased to levels of 2.4 to 2.9 fps and 3.2 to 3.4 fps respectively. These values for the transport of steel pieces are higher than the 2.5 fps reported in Reference 2 for scouring velocity. The earlier tests of Reference 2 were conducted with a batch of solids deposited in the pipe. The test series reported in this program was conducted with a continuous flow of solids and is therefore considered to be more representative of actual conditions.

Third Elbow. For all the conditions tested, the scouring velocity at the third elbow was found to be significantly higher than that required for the straight pipe, with a still larger

TABLE III

SCOURING VELOCITY DATA (A)

(6" diameter, 45° siphon; 5' sloping legs with 10' horizontal run)

Test Conditions				Scouring Velocity (ft/sec)				Comments
	Heavy Solids			At Straight Pipe		At Third Elbow		
Suspended Refuse Concentration (%)	Material	Feeding Rate (lb/min)	Bulk S.G. (gr/cc)	Initial Scouring Velocity	Clean Out Velocity	Initial Scouring Velocity	Clean Out Velocity	
0.0	Sand	5	1.5	1.0	2.3	2.3	2.9	Effects of Individual Refuse Components
	Glass	5	1.5	1.0	2.3	2.3	2.9	
	Metal Chip	5	4.3	2.9	3.2	3.4	4.6	
	EPA Solids	6	1.3	2.4	3.4	3.4	4.6	Mixture Effects
	Sand & Glass	5	1.5	1.7	2.3	2.3	2.7	
	Sand & Glass	20	1.5	2.3	2.7	2.7	3.4	Feeding Rate Effects
	Metal Chip	12	4.3	2.9	3.4	4.2	4.6	
1.0%	Sand & Glass	5	1.5	1.7	2.3	2.3	2.9	Effects of Suspended Refuse
	Metal Chip	5	4.3	-	3.4	3.4	4.6	
	EPA Solids	10	1.3	2.9	3.4	3.4	4.3	

TABLE IV

SCOURING VELOCITY DATA

(EPA Refuse Only)

Siphon Angle (Degrees)	Suspended Refuse Concentration (%)	Solids Feeding Rate (lb/min)	Scouring Velocity (ft/sec)				Average Maximum Scouring Velocity (ft/sec)
			At Straight Pipe		At Third Elbow		
			Initial Scouring	Clean Out Velocity	Initial Scouring	Clean Out Velocity	
60	0	10	2.3	2.9	3.4	4.6	4.6
		4	2.3	2.9	3.4	4.6	
		6	-	2.9 ~ 3.4	3.4	4.6	
45	0	6	2.4	3.4	3.4	4.6	4.45
	1.0	10	2.9	3.4	3.4	4.3	
22 1/2	0	6	2.3	2.9	3.4	3.8	3.8
	1.0	6	2.3	2.9	3.4	3.8	

velocity increase required for steel chips. Initial scouring and clean out velocities for glass and sand were 2.3 and 2.9 fps respectively. Similar velocities for metal pieces were 3.4 to 4.2 feet per second and 4.3 to 4.6 fps respectively.

Effect of Siphon Angle. The souring velocity required in the siphon is relatively independent of siphon angle. The maximum velocity required for clean out is approximately 4.6 fps for the 60° and 45° siphons but drops to 3.8 fps for the 22° siphon.

Effect of Heavy Solids Concentration. Over the range of solids concentration tested, i.e. as high as 1 percent heavy solids, the scouring velocity is relatively independent of concentration.

Effect of Material Density. The heavier metals require a higher velocity (3.4 fps for the straight pipe and 4.6 fps at the siphon elbow) than the lower density glass and sand (2.3 fps for the straight pipe and 2.7 fps for the siphon elbow). Aluminum pieces in the EPA solids behaved much like sand and glass.

Effect of Refuse Concentration. The scouring velocity for heavy solids is relatively independent of the refuse concentration of the slurry. No significant change was observed up to a refuse concentration of 1 percent.

Conclusions

From this series of tests on the flow of ground refuse slurries through inverted siphons it is concluded that,

(1) The normal sewer design velocity of 2.5 fps is adequate to transport materials such as ground glass and sand. Aluminum being approximately of the same density is also transportable. Steel cans ground in a hammermill and small steel chips require a higher velocity of 3.4 fps to ensure self cleaning. Transport by saltation is possible at a velocity of 2.5 fps but is likely to be hazardous. Steel cans should therefore be excluded from the refuse slurry transport system.

(2) The siphon system requires a minimum clean out velocity of 3.4 fps for sand, glass and aluminum and 4.6 fps for steel. These values are higher than the 2 to 3 fps used in normal design practice and consequently solids deposition will occur. However, in the siphon, which always flows full, the formation of such deposits is self-stabilizing. The deposit layer will build up to a depth such that the local flow velocity over the deposit layer reaches the clean out velocity. At this time, no further heavy solids deposition would take place.

The deposited layer acts as a constriction in the pipe and produces an increase in the pressure drop through the siphon. For a typical flow condition where the siphon is designed for a normal velocity of 2.5 fps and the clean out velocity required is 4.6 fps, the deposited layer would result in an increase in pressure drop of 0.7 inches of water. If steel chips are excluded, the clean out velocity would be reduced to 3.4 fps and the pressure drop to 0.4 inches of water. These values represent an insignificantly small increase in the total head loss in the sewer system. For a sewer having a 0.002 gradient, the 0.7 inch of water head loss is equivalent to an extra 30 feet in sewer length.

(3) The flow of ground refuse slurries at normal velocities of greater than 2 fps and refuse concentrations up to 1 percent by weight do not result in any increase in the head loss through the siphon. Thus normal siphon design should be adequate to transport the ground refuse slurry.

CHAPTER 4

RUNNING TRAP EVALUATION

Building sewers may have a running trap, as shown in Figure 16, to trap and collect heavy solids. The effect of refuse concentration and heavy solids on the performance of the running trap was investigated.

Experimental Facility and Test Procedures

A schematic drawing of the running trap flow facility is shown in Figure 17. The test section includes a solids feeder inlet, 10 foot of 6" glass pipe, a reducer tee mounted vertically, the 6" running trap and additional 6" glass pipe. A photograph of the running trap installation is presented in Figure 18. The entire test section was secured to a rigid truss section to insure uniform slope along the test section. This slope was adjustable from 0.0 to 0.012 and permitted the independent variation of flow rate and flow depth or velocity.

The depth of flow was monitored at four locations as shown in Figure 17. Station 2 employed the glass tee with vertical outlet to permit monitoring of the static head in full flow situations.

Measurement of the flow depth at the inlet and outlet to the running trap, stations 2 and 3 of the flow loop, was used to determine the head loss. The head loss across the running trap was determined from the energy equation as

$$H_L = \frac{1}{2g}(V_2^2 - V_3^2) + (h_2 - h_3) + s\, l_r \qquad (1)$$

where

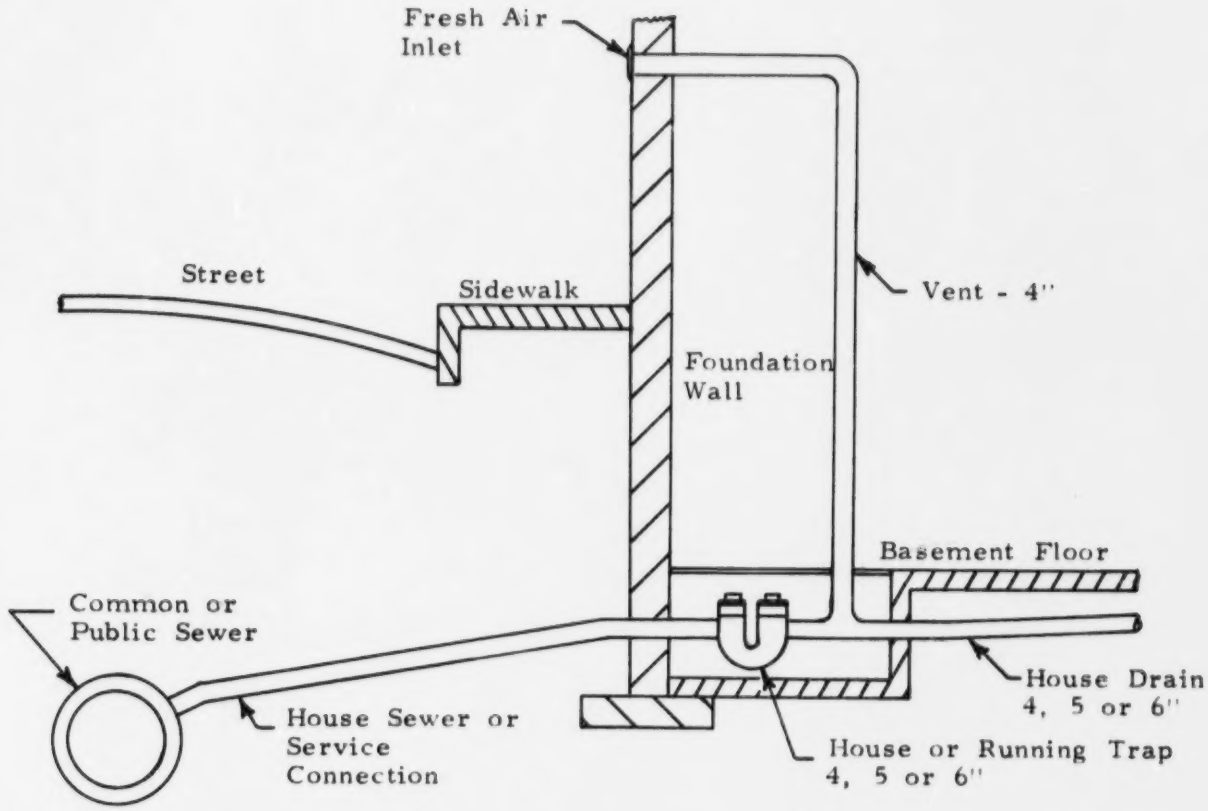
V_2, V_3 are the flow velocities at stations 2 and 3 respectively

h_2, h_3 are the flow depths at locations 2 and 3 respectively

s is the pipe slope

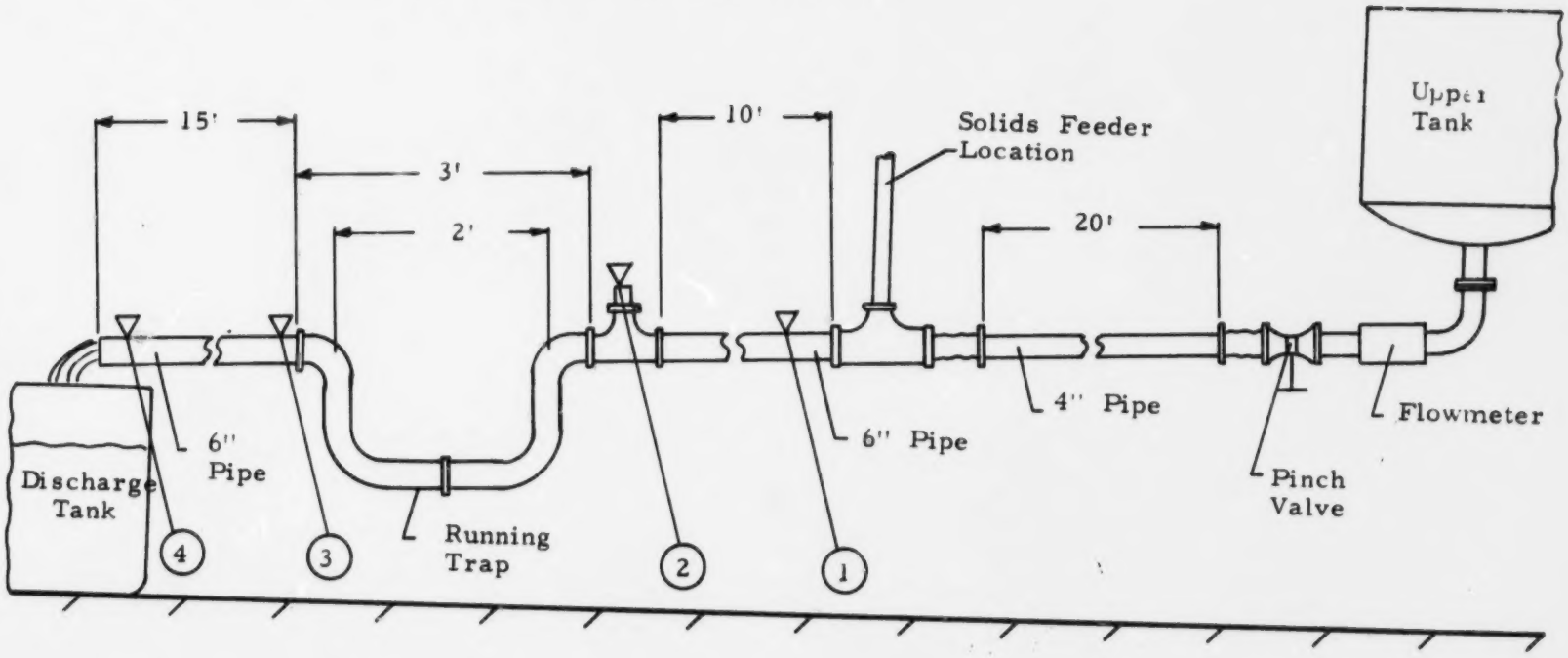
l_r is the distance between the measurement stations.

More conventionally the head loss through bends and other geometries is expressed in terms of the inlet velocity head and a loss coefficient, such as,



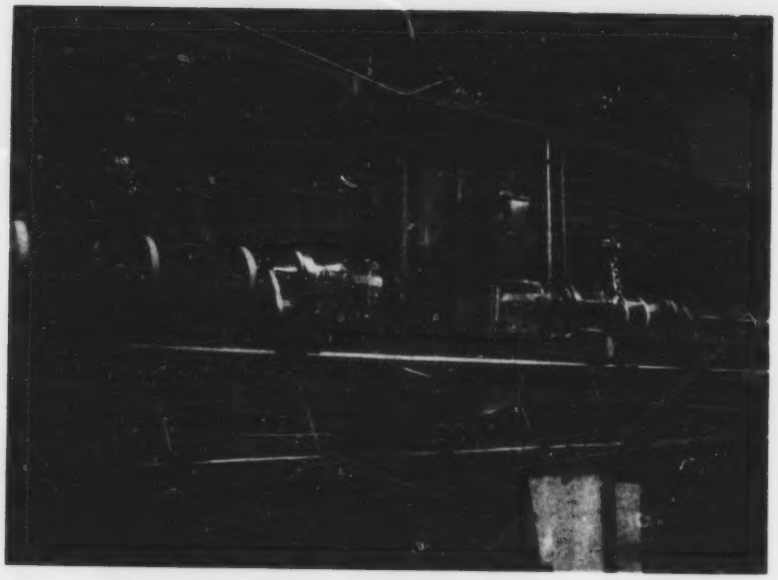
A Typical Drainage System Connecting Building to Sewer

Figure 16



Flow Facility For Running Trap Tests

Figure 17



Running Trap Installation

Figure 18

$$H_L = k_t \left(\frac{V_2^2}{2g}\right) \qquad (2)$$

For the 6 inch pipe, this is expressed as

$$k_t = \frac{4.16\ H_L}{(Q/100)^2} \qquad (3)$$

where

H_L is the head loss in inches

Q is the flow rate in gpm

The initial scouring velocity was determined by feeding heavy solids at a fixed rate and measuring the minimum flow velocity required to continuously clear the solids without accumulation. The clean out velocity was determined by depositing a pile of heavy solids in the trap and measuring the minimum velocity required to disperse and slide the pile downstream. Solids ground in the hammermill at the EPA laboratories were used.

Experimental Head Loss Results

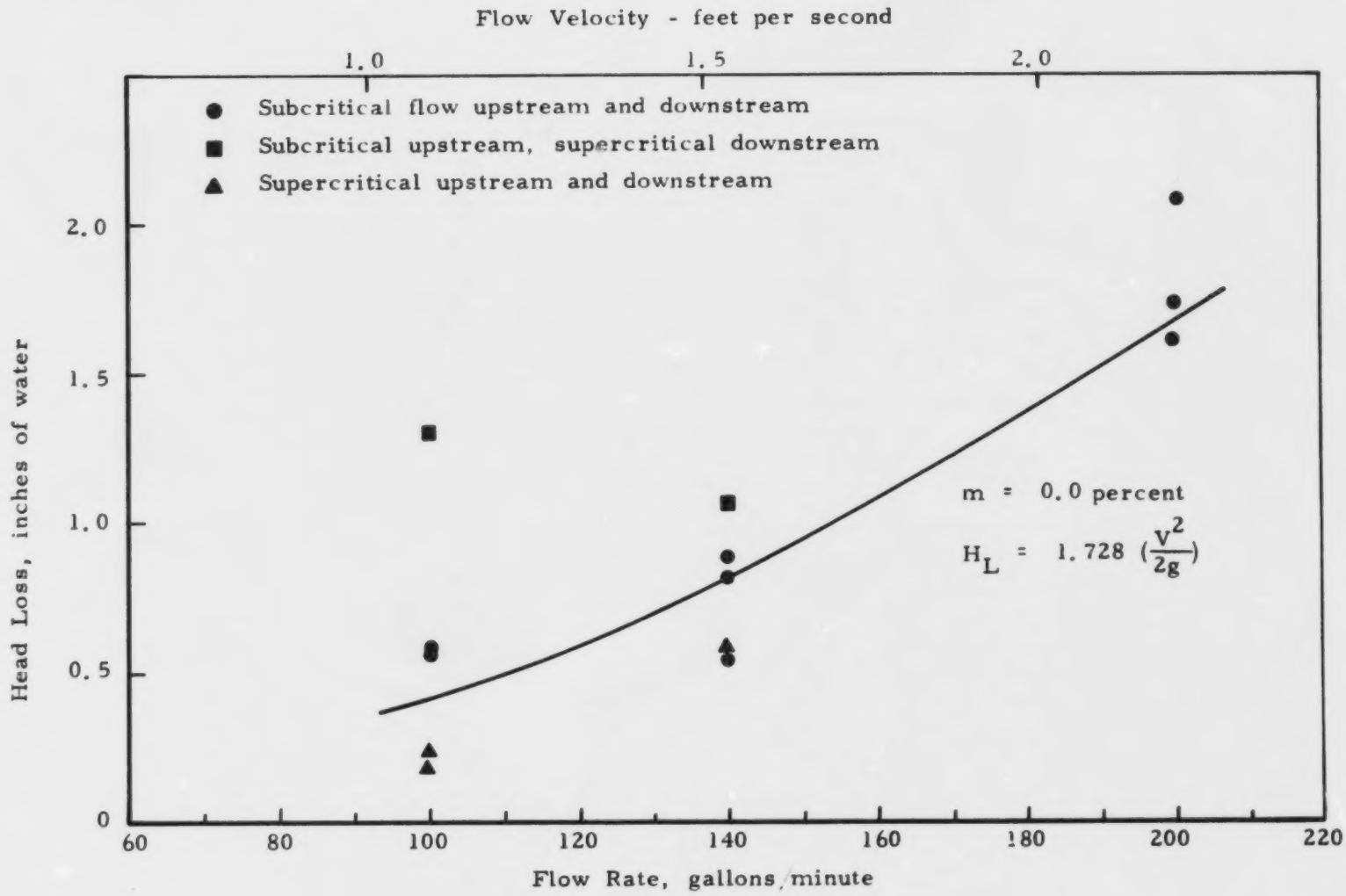
Using Equations 1 and 2, the head loss, H_L, and head loss factor, k_t, were computed from the flow data. Partial flow occurs in both the inlet and outlet to the running trap. Flow may be either subcritical or supercritical in the inlet or outlet. Since the head loss characteristics are strongly affected by the type of flow the following three cases were considered separately.

(a) Inlet and outlet both subcritical flow

(b) Inlet subcritical and outlet supercritical

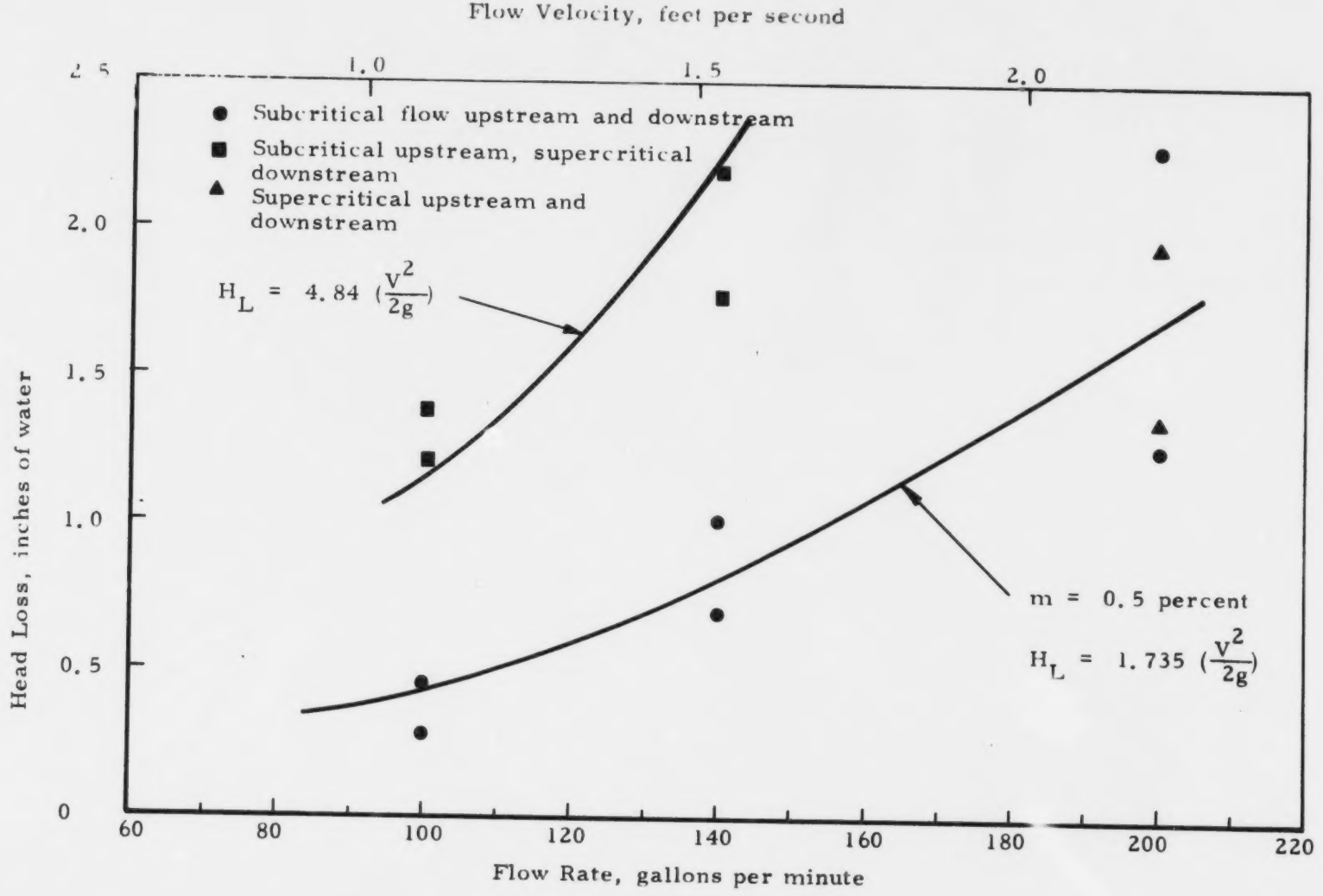
(c) Inlet and outlet supercritical flow

The head loss data for the running trap at various refuse concentrations, is presented in Figures 19 through 22 as a function of velocity. Also presented in these figures are the curves based on average k_t values calculated from the head loss data. The k_t values for a wide range of flow rates, refuse concentrations and flow conditions are tabulated in Table V. Table V shows the variation of k_t with refuse concentration for the various flow conditions.



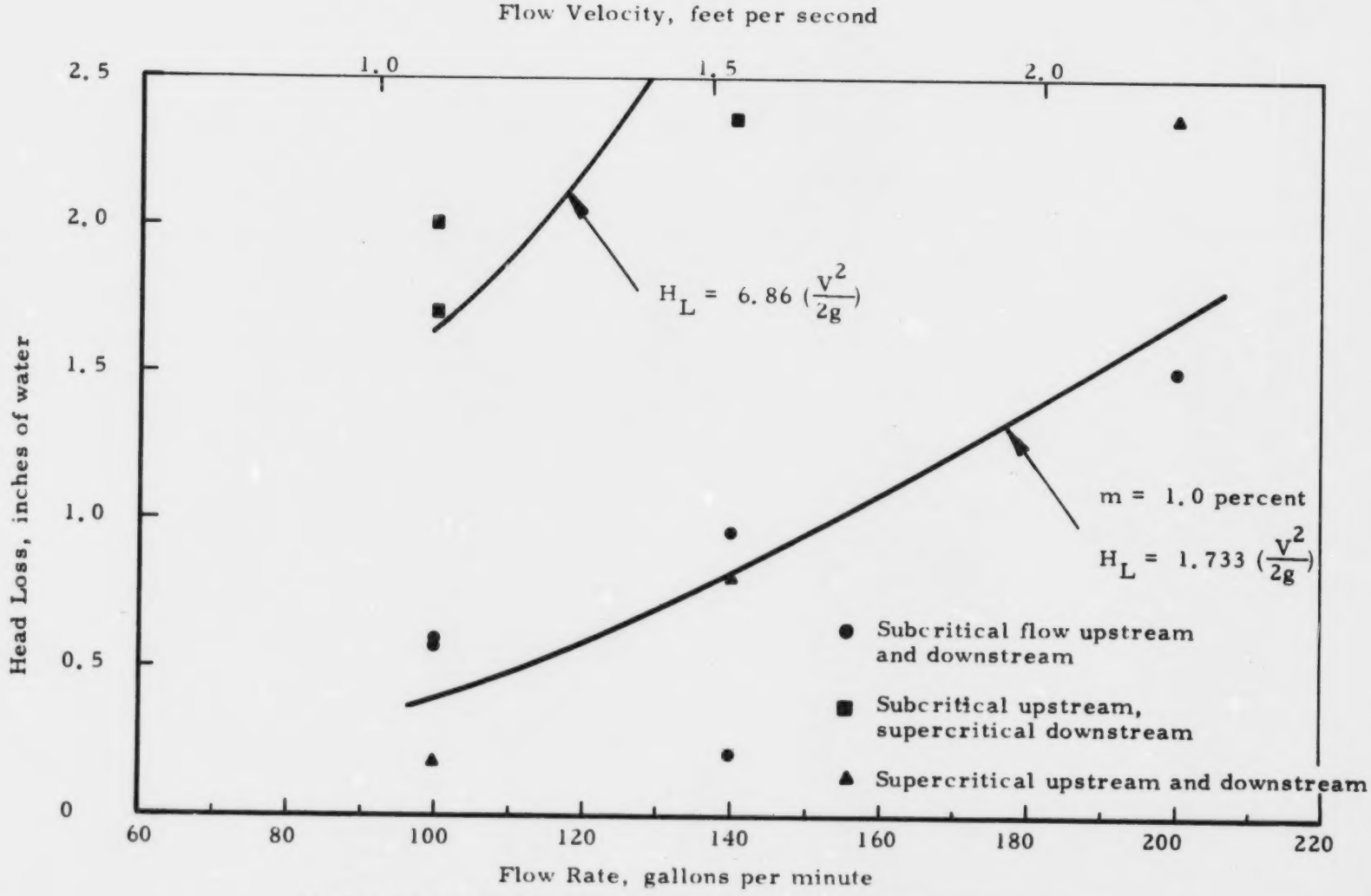
Head Loss Characteristic For 6" Running Trap - Clear Water

Figure 19



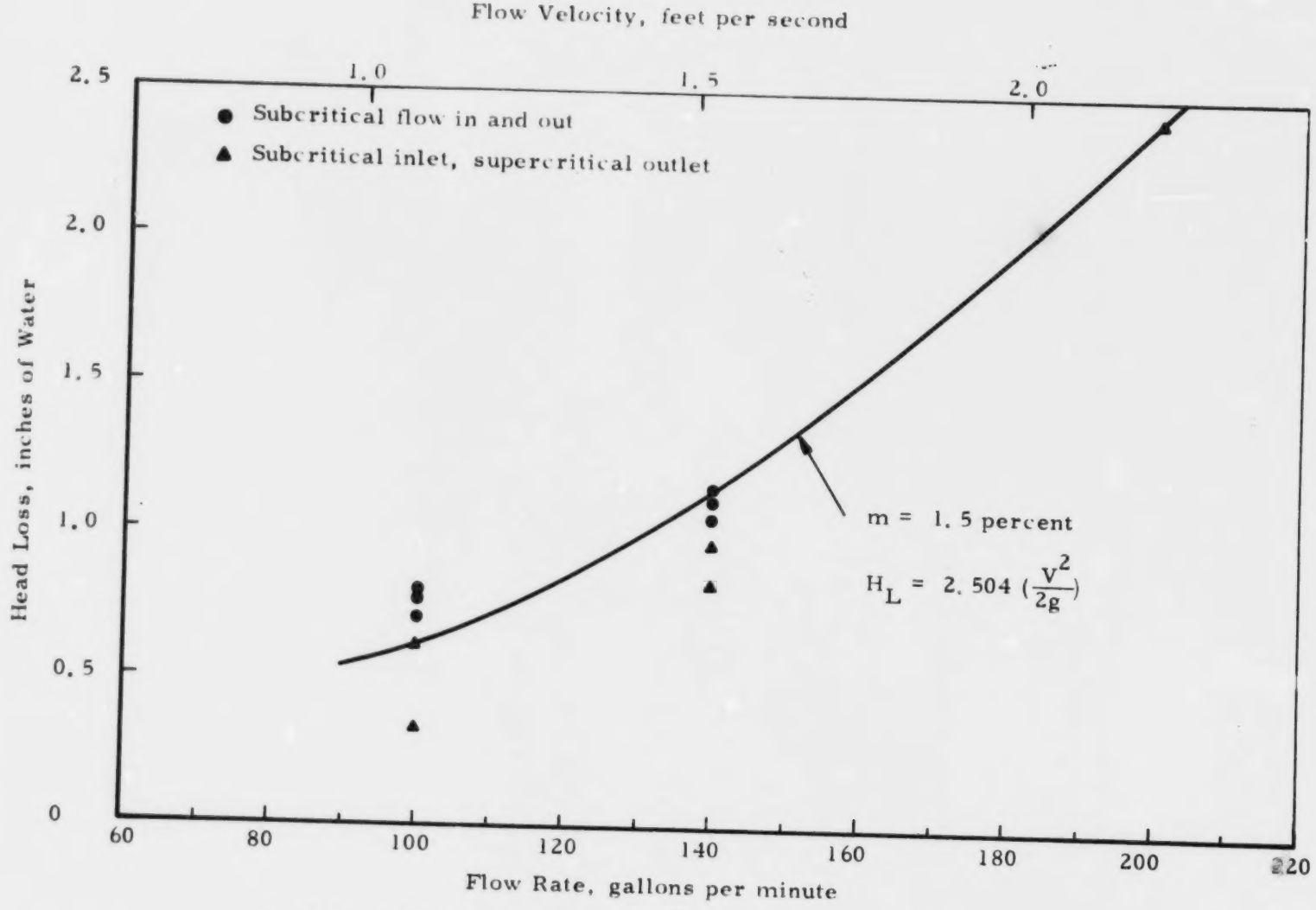
Head Loss Characteristic for 6" Running Trap 0.5 percent Refuse

Figure 20



Head Loss Characteristic for 6" Running Trap 1.0 percent Refuse

Figure 21



Head Loss Characteristic for 6" Running Trap 1.5 percent Refuse

Figure 22

TABLE V

AVERAGE HEAD LOSS FACTOR, k_t, FOR RUNNING TRAP

Flow Condition		Average Head Less Factor, k_t			
Upstream	Downstream	m = 0	m=0.55	m= 1.1	m= 1.5
Subcritical	Subcritical	1.728	1.735	1.733	2.504
Subcritical	Supercritical				
Supercritical	Supercritical	2.26	4.84	6.86	-

From the results of this investigation the following significant conclusions are made:

(1) Head loss through the running trap is a strong function of the inlet flow conditions. The head loss for supercritical flow at the inlet is considerably higher than for subcritical flow at the inlet because of the turbulence created by the inlet velocity of 4 to 5 fps. The subcritical inlet velocities of 2 to 3 fps cause only a mild swirl at the trap inlet with a proportionately lower head loss.

(2) With subcritical flow at the inlet, the head loss factor k_t and hence the head loss through the running trap remains essentially constant and independent of refuse concentration up to 1.1 percent. For higher refuse concentrations, such as 1.5 percent, the head loss coefficient increases from 1.73 to 2.5 representing a 50 percent increase in the head loss with clear water. Thus, to minimize the effect of refuse concentration on head loss the refuse concentration in the slurry should be limited to 1 percent.

(3) Refuse concentration has a severe effect on the head loss when the inlet flow is supercritical. With a refuse concentration of 0.55 percent the head loss factor is double that of water alone and it is three times as high for a refuse concentration of 1.1 percent. Supercritical inlet flow should therefore be avoided. However, in a actual gravity flow sewer system supercritical inlet flow is unlikely to occur and consequently this effect is of no practical concern.

Experimental Scouring Velocity Test Results

Scouring velocity tests were performed on the running trap system in a manner similar to the inverted siphon system. Initial scouring velocity and clean out velocity were determined for the inlet pipe and the trap itself using the EPA heavy solids. The data is presented in Table VI.

The results indicate that:

(1) A velocity of 3.5 ft/second is satisfactory for clean out for all slopes and mixture concentrations.

(2) The scouring velocities reported for the inlet pipe to the running trap are less than those reported for the inlet to the inverted siphon. This is due to the slope of the inlet to the running trap not the partial flow situation. In general, full flow scouring velocities are less than those for the partial flow case.

TABLE VI

SCOURING VELOCITY OF RUNNING TRAP

(EPA Solid Refuse)

Slope	Suspended Refuse Concentration	Solids Feeding Rate (lb/min)	Scouring Velocity (ft/sec)			
			Straight Pipe		Running Trap	
			Initial	Clean Out	Initial	Clean Out
0.006	0.0	5	1.75	2.9	3.4	3.6
0.006	0.55	5	1.75	2.9	2.9	3.4
0.006	1.1	5	1.8	2.9	2.9	3.4
0.006	1.50	5	1.7	2.9	3.4	3.7
0.008	0.0	5	1.2	2.3	2.9	3.55
0.010	0.0	5	1.2	2.9	2.9	3.60
0.012	0.0	5	1.2	2.9	2.9	3.5
Average Velocity			1.7	2.9	2.9	3.5

The scouring velocities for the running trap are considerably lower than those for the inverted siphon due to the severe turbulence of the flow.

CHAPTER 5

ELBOW EVALUATION

Experimental Facility and Test Procedures

Head loss and scouring characteristics were evaluated for flow through 6" diameter bends of 22-1/2°, 45° and 90°. The experimental facilities for the 22 1/2° and 45° bends are similar and are shown schematically in Figure 23. The 90° bend facility is different and is shown in Figure 24. Photographs of the three systems are presented in Figure 25.

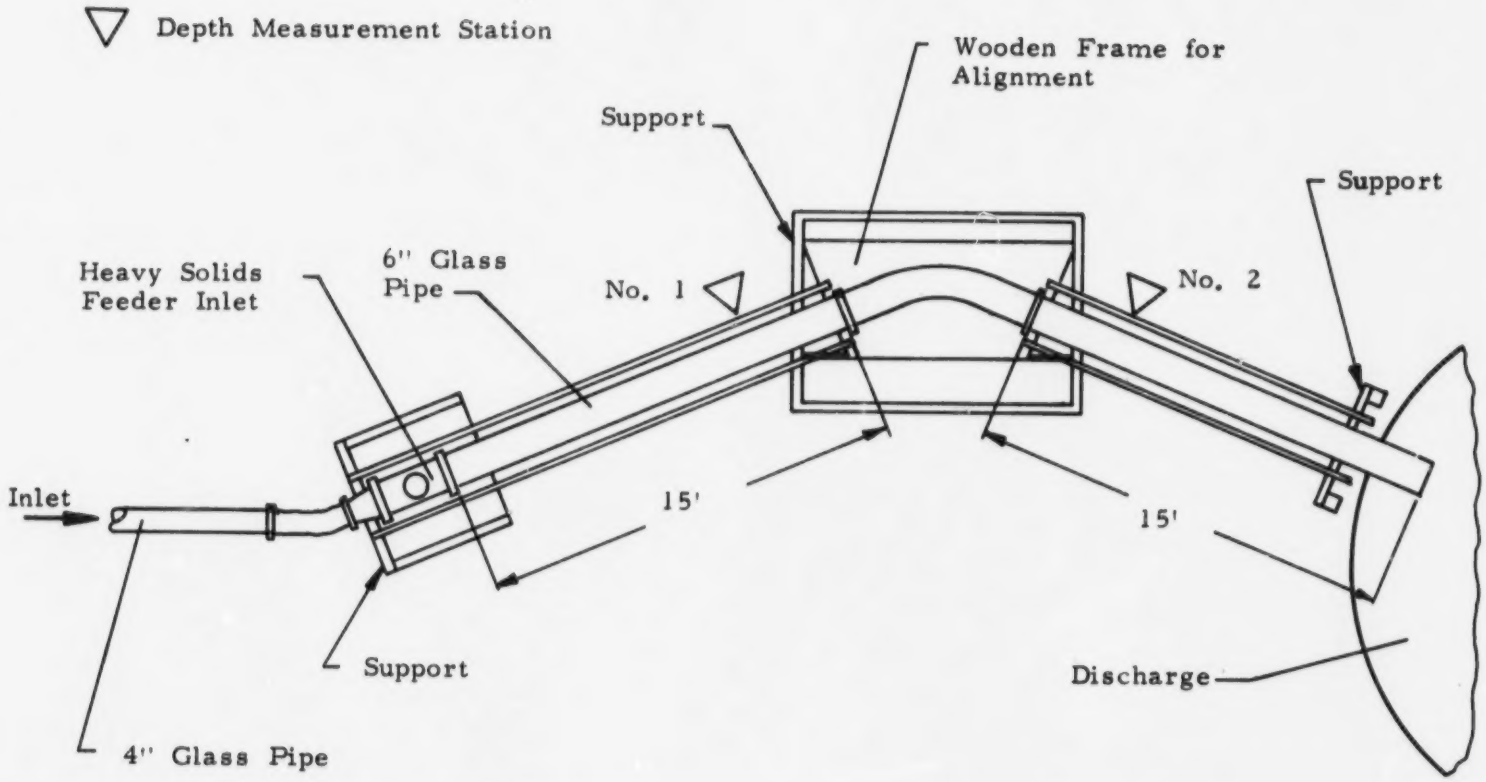
The test loop included the solids feeder, 15 or 20 feet of glass inlet pipe, the test bend and 15 or 20 feet of outlet pipe. Slope changes were made about the center of the bend. Depth measurement stations were designated near the inlet and outlet of the bend as shown in Figure 23. At both stations the depth of flow was monitored visually using a depth gage mounted on the glass pipe.

The test procedure followed was similar to that for the running trap tests. A wide range of flow rates and velocities was achieved by changes in slope of the pipe from 0.0 to 0.012. The solids were fed at a steady rate in the usual manner and the accumulation monitored visually.

Measurements of the flow depth at the inlet and outlet of the bend were used to determine the head loss using Equation 1 of Chapter 4. The head loss was expressed in terms of the head loss factor k_b similar to the k_t of Equation 2.

Experimental Head Loss Results

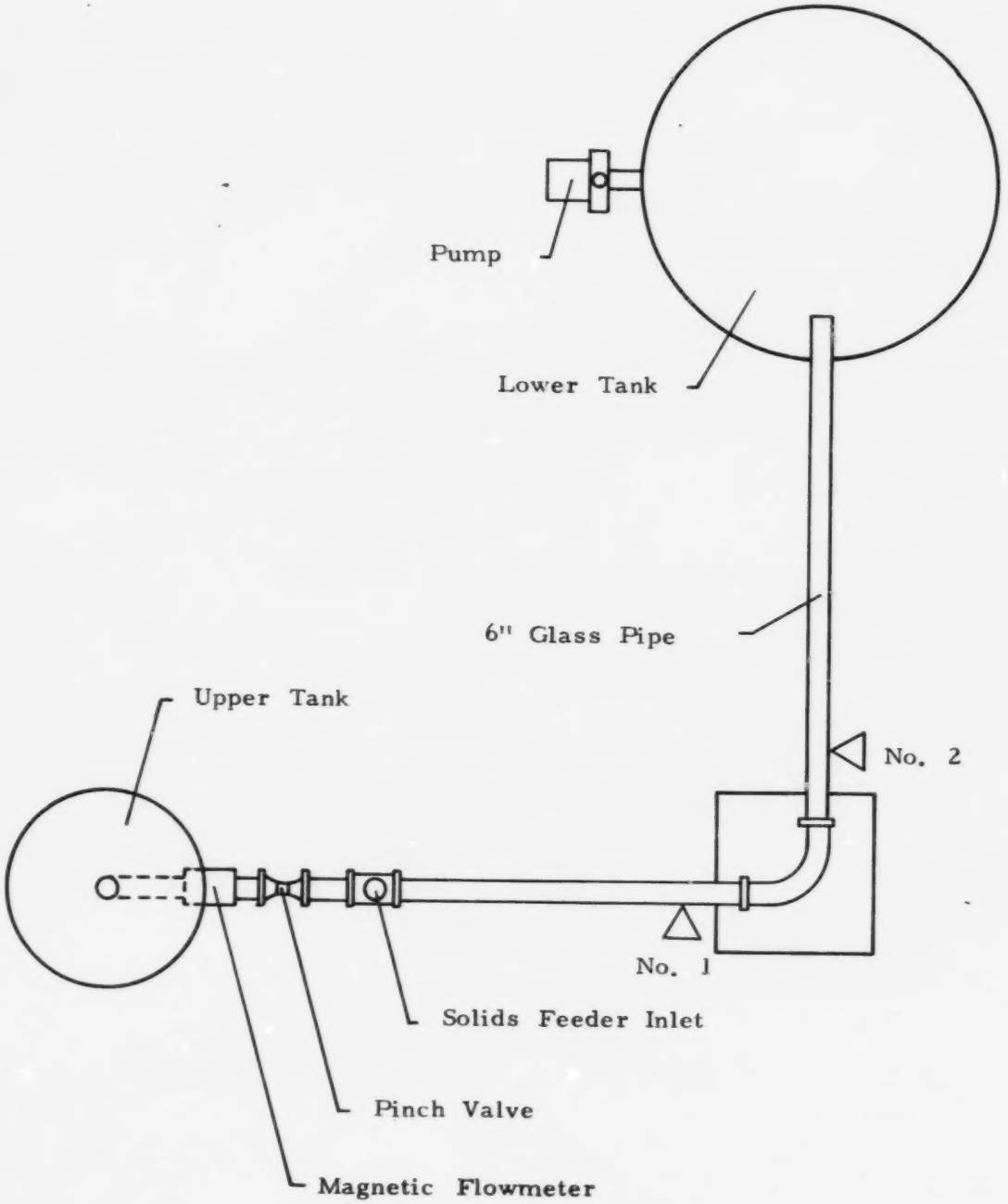
The head loss, H_L, and head loss coefficient, k_b, were computed from the measured flow data using Equations 1 and 2. The head loss coefficient was then used to generate the average curves of head loss presented for 22 1/2°, 45° and 90° elbows in Figures 26, 27 and 28 respectively. For the elbows, the nature of the inlet flow - namely subcritical or supercritical - was found to have little effect on the head loss. Consequently, the head loss for a specific elbow geometry and refuse concentration is independent of inlet conditions and may be represented by a single curve and head loss coefficients as presented in Table VII.



22 1/2° and 45° Elbow Test Loop Diagram

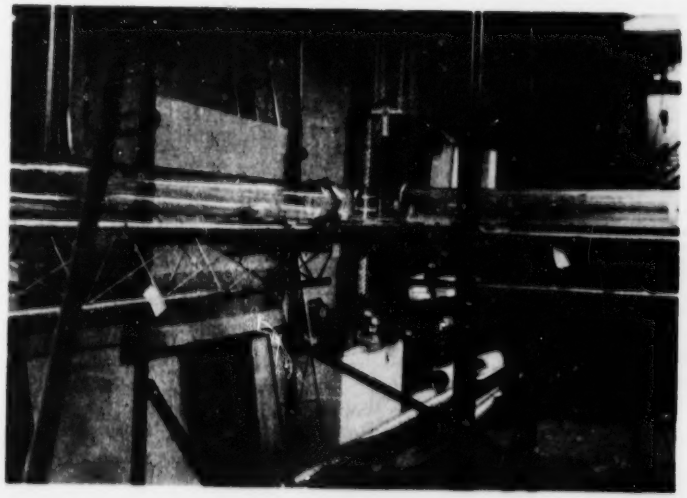
Figure 23

△ – Depth Measurement Station

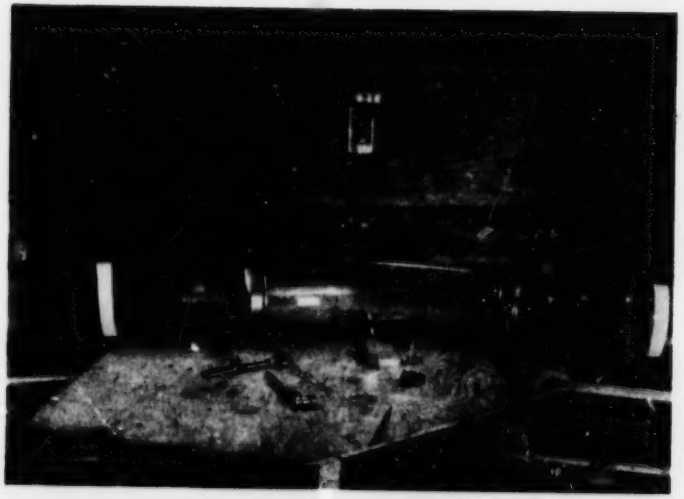


90° Elbow Test Loop Diagram

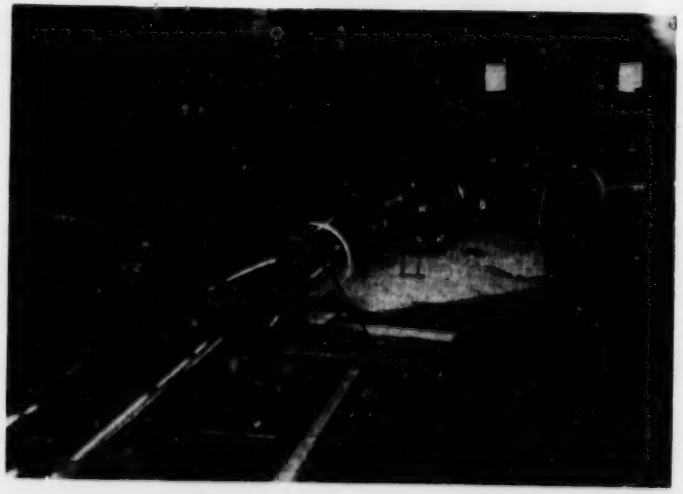
Figure 24



(a) 90° Elbow



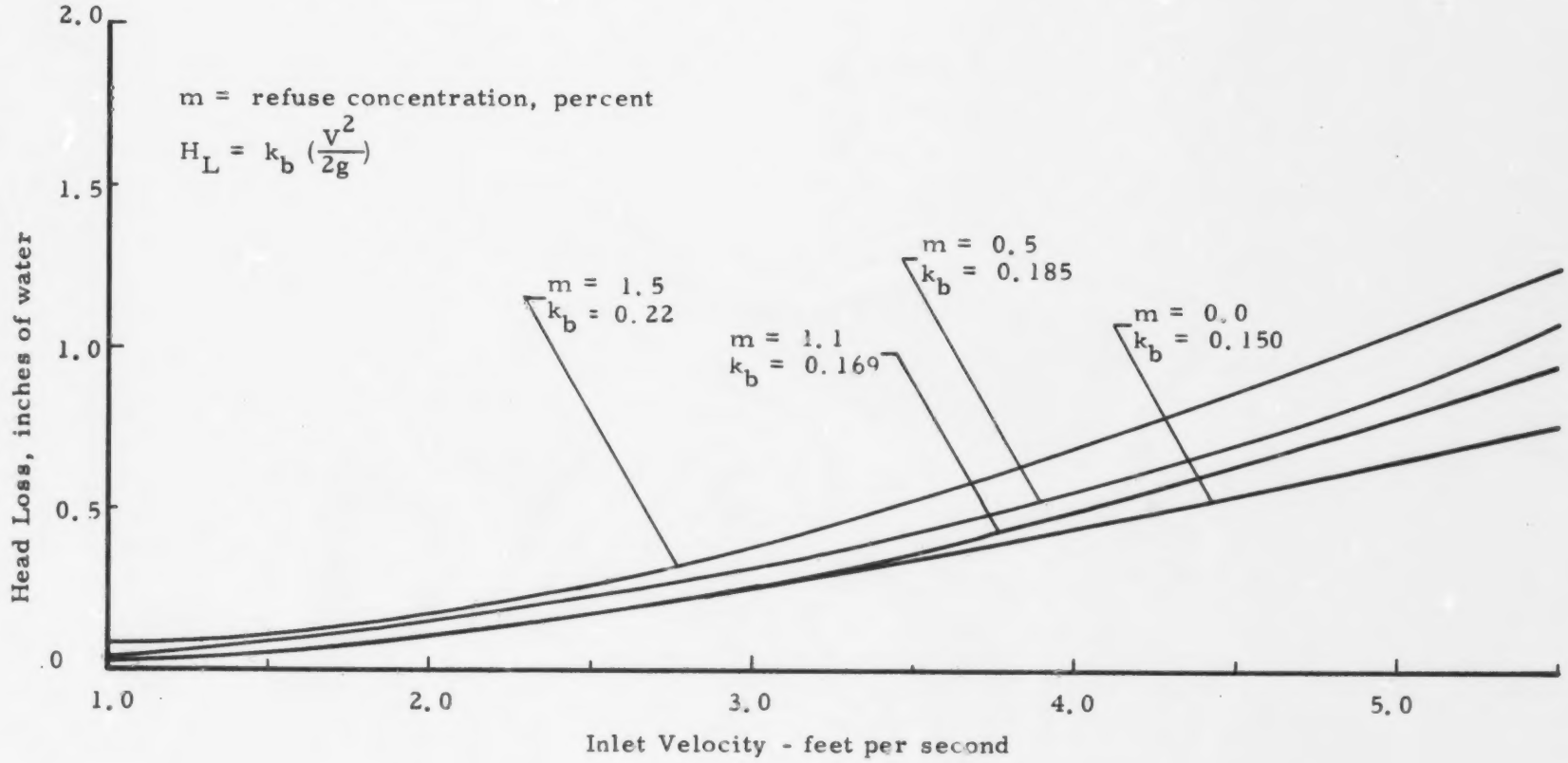
(b) 22 1/2° Elbow



(c) 45° Elbow

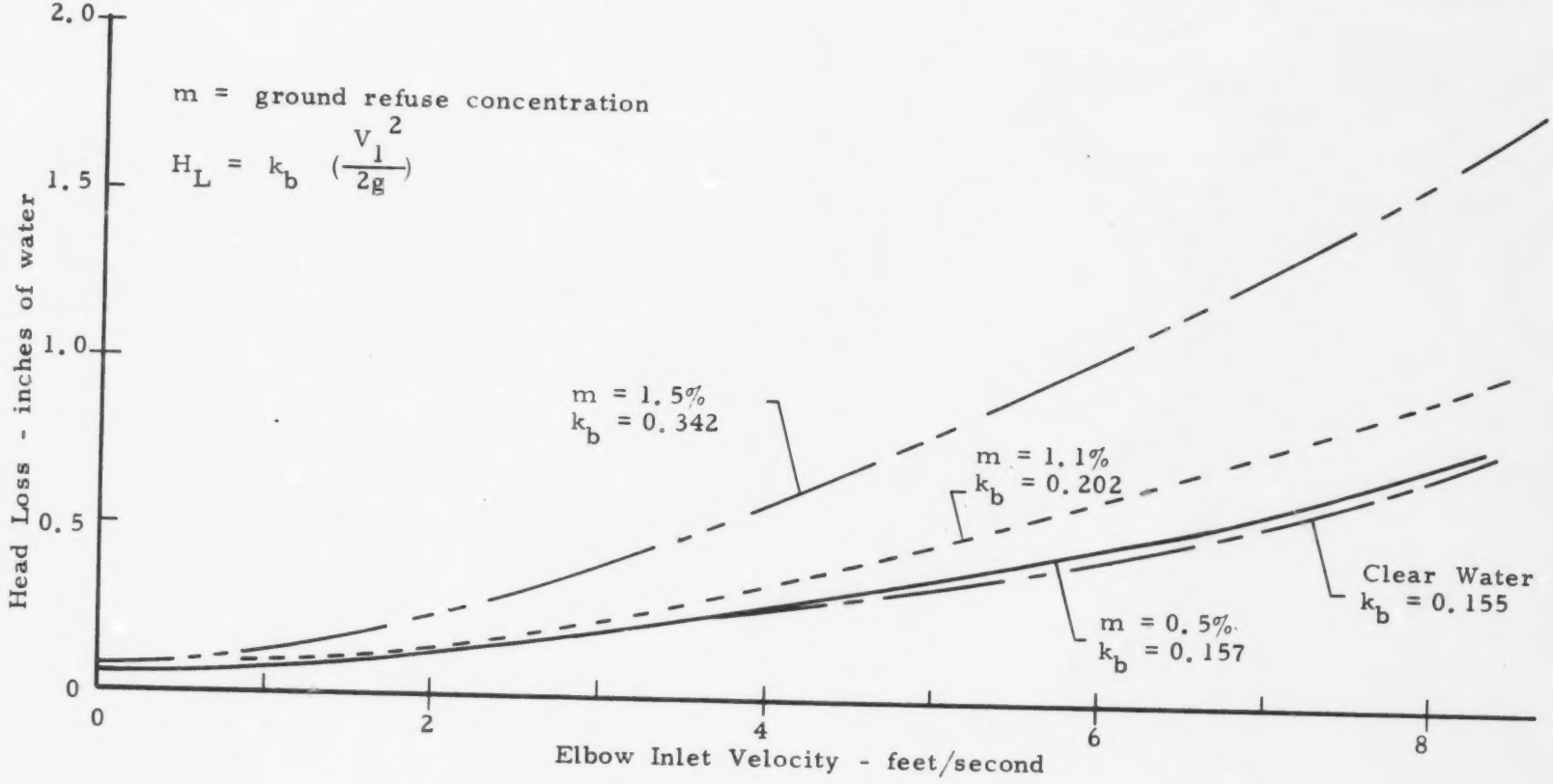
Elbow Installations in Test Loop

Figure 25



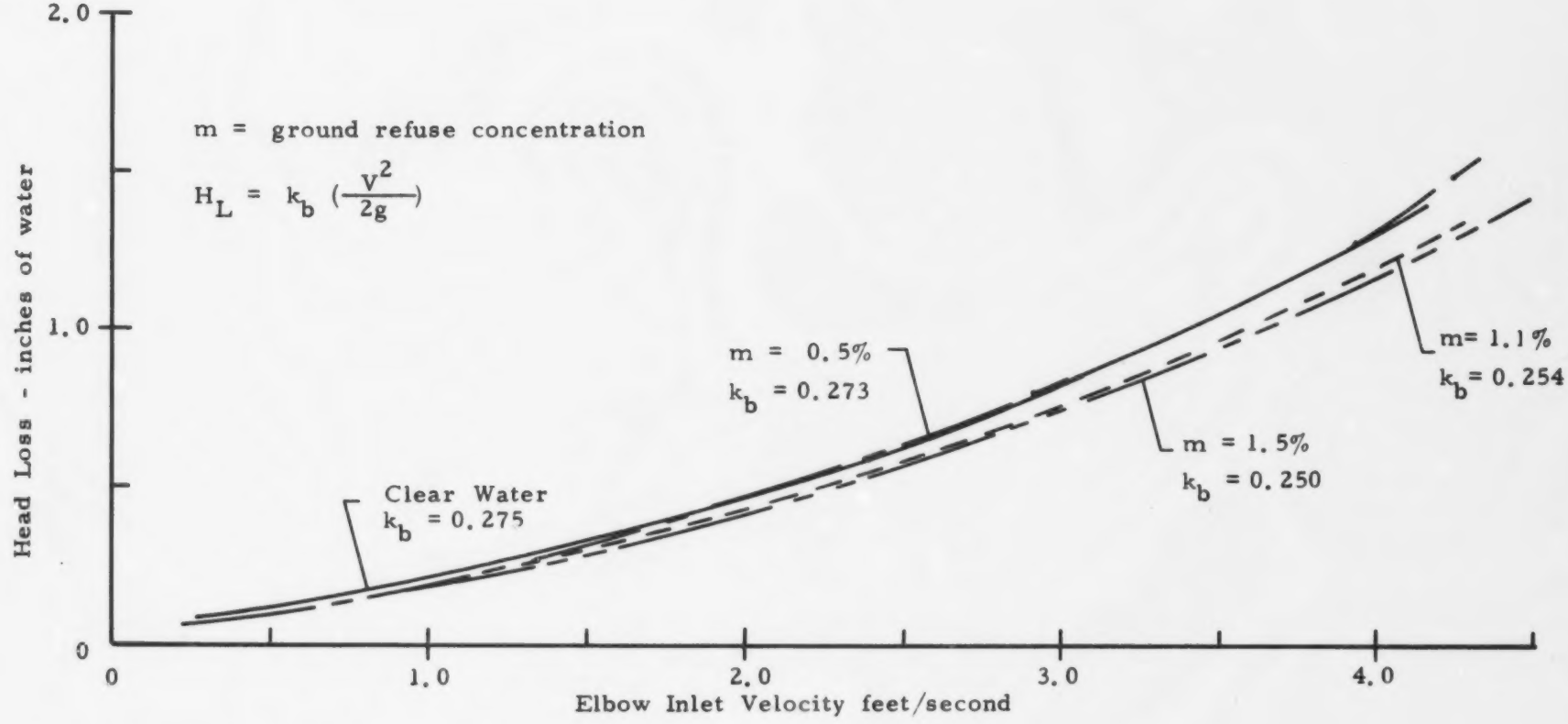
Head Loss Characteristics for 22 1/2° Elbow

Figure 26



Head Loss Characteristics for 45° Elbow

Figure 27



Head Loss Characteristics for 90° Elbow

Figure 28

TABLE VII

HEAD LOSS COEFFICIENTS FOR ELBOWS

6" Diameter Pipe

Angle of Elbow	Head Loss Coefficient, k_b			
	Refuse Concentration, Percent			
	0.0	0.5	1.0	1.5
22 1/2°	.150	.19	.17	.22
45°	.155	.157	.202	.342
90°	.275	.275	.254	.250

From the results of the investigation the following conclusions may be drawn:

(1) Head loss through the bends is not strongly affected by the nature of the inlet flow - either subcritical or supercritical.

(2) Head loss is essentially independent of refuse concentration up to and including 1.0 percent for all the elbow geometries tested.

(3) At 1.5 percent refuse concentration, the 22-1/2° and 45° elbows did show significant increases in head loss, particularly at extremely low velocities on the order of 1 foot per second. No significant increase in the head loss was experienced for the 90° elbow at 1.5 percent.

Experimental Scouring Velocity Test Results

Scouring velocity tests were performed using the 22-1/2", 45° and 90° elbow geometries. Mixtures of sand and crushed glass were tested in addition to the standard EPA solids mixture described in Table I, page 12. The test program included various combinations of feeding rates, pipe slopes and refuse concentrations. The details of each test are presented in Table VIII.

The data presented in Table VIII includes both the initial scouring velocity and the clean out velocity in the vicinity of the bend. For comparison, the velocities required in the straight pipe upstream of the bends are presented as well. The straight pipe data is typical of the Phase I results.

In general, the velocities required for scouring in the vicinity of the bend are similar to those required for effective scour in the upstream straight pipe. There is a slight tendency for heavy particles to settle out due to reduced velocities near the bend. This is almost completely nullified by the turbulence in the flow in the bend and the straight pipe beyond. The turbulent flow scours heavy solids from the bottom into the higher velocity flow. The level of the turbulence increases with the severity of the bend. For the 90° elbow the turbulence was evident even at very low flow rates. At velocities typical of practical applications the turbulence was such that no solids settled in the bend. For this reason no data from the 90° elbow test appears in Table VIII.

From the scouring velocity tests were concluded:

(1) For the 22-1/2° and 45° elbows, the initial scouring velocities and clean out velocities are approximately equal to the velocities required in a straight pipe of similar characteristics.

TABLE VIII

SCOURING VELOCITY TESTS - ELBOW EVALUATION

Test Conditions					Scouring Velocity ft/sec			
					Straight Pipe		In Bend	
Type of Bend	Suspended Refuse Concentration	Slope of Pipe	Type of Heavy Solids	Feeding Rate	Initial Scouring Velocity	Clean Out Velocity	Initial Scouring Velocity	Clean Out Velocity
45°	0%	0.006	Sand & Glass	10 lb/min	2.4	2.6	2.6	2.7
45°	0%	0.006	EPA Solids	5 lb/min	2.5	2.7	2.6	2.9
45°	0%	0.008	EPA Solids	5 lb/min	2.5	2.7	2.5	2.9
45°	0%	0.010	EPA Solids	5 lb/min	2.5	3.0	2.6	2.8
22 1/2	1.0%	0.004	EPA Solids	5 lb/min	2.0	2.3	2.3	2.4

(2) Heavy solids did not settle in the 90° bend over the normal range of flow conditions.

(3) In general, heavy solids will not accumulate excessively in horizontal bends. The turbulence due to the change in flow direction improves the ability of the flow to scour.

CHAPTER 6

MANHOLE EVALUATION

Manholes are used in sewer practice for the following purposes:

(1) Provide a convenient access to the sewer for observation and maintenance operations.

(2) Minimize the hydraulic interference and energy loss due to transitions of slope, altitude, direction and size of pipes as well as at multipipe junctions.

The manhole generally consists of a "U"-shaped channel, bench, inlet connections and outlet connections. The effect of ground refuse and heavy solids on the performance of three manhole configurations was investigated. The manhole configurations included in the test program were:

(1) size transition channel

(2) straight channel

(3) 90° bend channel

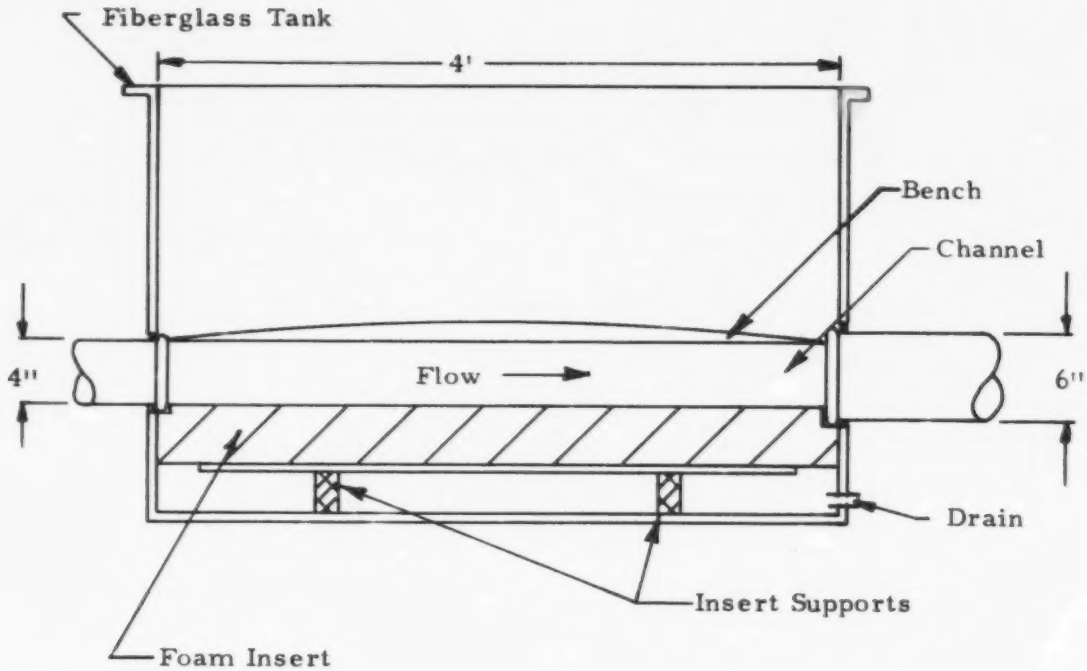
The detailed experimental investigation performed for these geometries provides an indication of the flow behavior to be expected in most manhole geometries.

In presenting the manhole flow study the three configurations will be discussed in general terms where possible followed by the details which differ from one geometry to the next.

Experimental Facility and Test Procedures

The manhole geometries were simulated for the laboratory flow loop using rigid urethane foam instead of concrete for the channel and bench. The foam inserts were placed in a vertical cylindrical fiberglass tank four feet in diameter. Holes through the side of the tank accepted the inlet and outlet pipes.

A cutaway view of the manhole with an insert in place is presented in Figure 29. Two of the foam inserts are shown photographically in Figure 30. Detailed schematics of the three inserts are presented in Appendix A.



Cutaway View of Simulated Size Transition Manhole

Figure 29

(a) Straight Channel

(b) Size Transition

Manhole Bench and Channel Inserts

Figure 30

The urethane foam inserts provided an inexpensive, light weight, easily modified model of manhole bench and channel geometries. The roughness of the foam surface is similar to the texture of concrete and therefore requires no additional preparation. A coat of dark paint was added however, to provide contrast with the lighter colored refuse flow and thus aid in visualization of the flow behavior.

The simulated manhole was mounted in the flow facility as shown in Figure 31. The installations were virtually identical for the straight channel and size transition channel. For the size transition channel the inlet was through a 4" glass pipe and the outlet through a 6" glass inlet pipe.

For the 90° manhole, flow entered and exited through the walls of the fiberglass tank at an angle of 90° as shown in the plan view of Figure 32. In all other respects the set ups were identical. The slope of the channel was the same for each manhole and fixed throughout the test program at 0.025. The slopes of the inlet and outlet pipes were independently adjustable.

The solids feeder was mounted in the inlet pipe at the entrance to the test section. Three depth measurement stations were established - one in the inlet pipe, one mid channel in the manhole and one in the outlet pipe approximately as shown in Figures 31 and 32. The measurements were made by observing the depth of flow using a scale mounted on the pipe and in the channel.

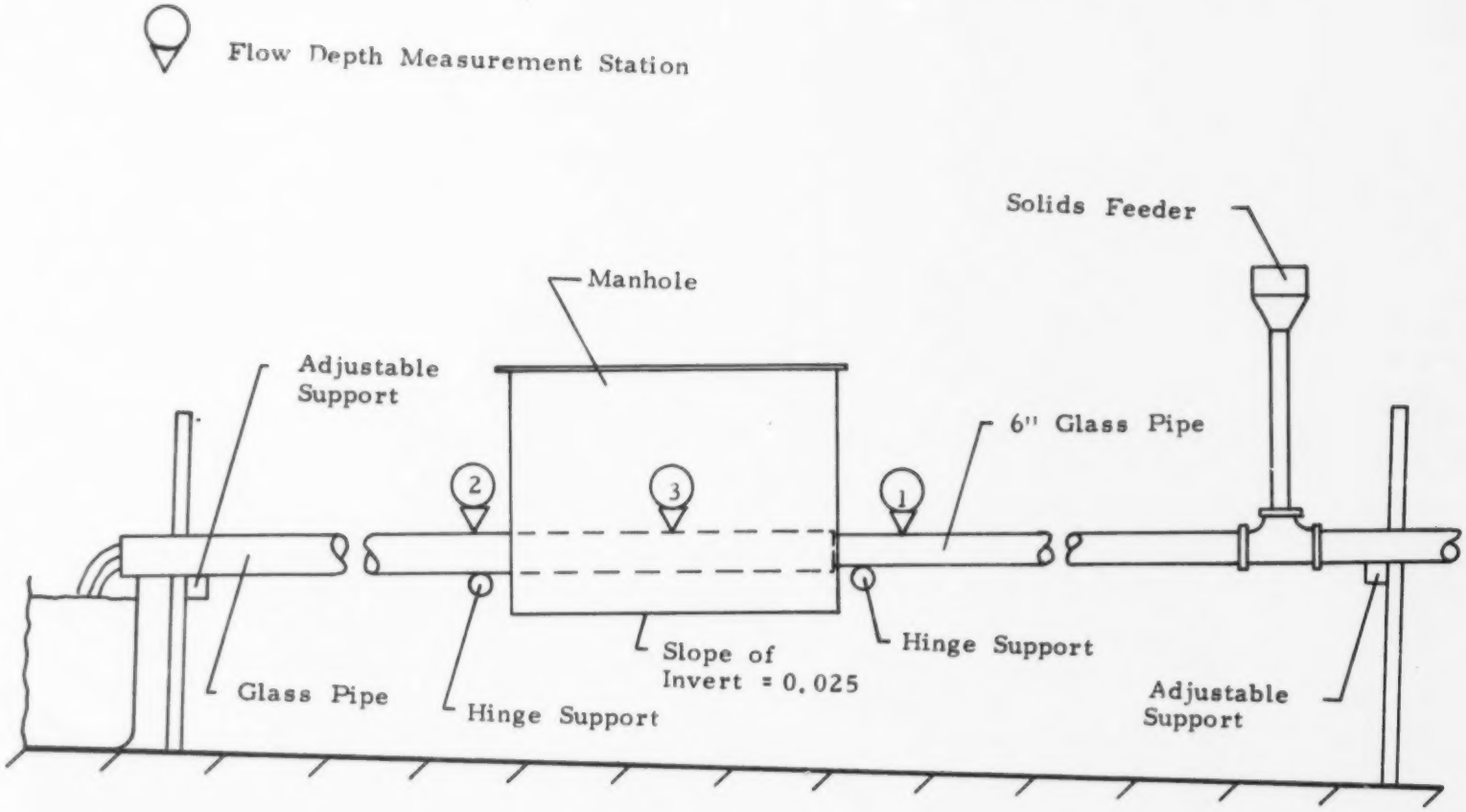
Photographs of the test setup for all three manhole configurations are presented in Figures 33, 34 and 35.

The independently adjustable slopes of the inlet and outlet pipes result in a wide range of possible combinations. The slope combinations selected for the straight channel and the size transition channel tests are presented in Table IX. The slope combinations tested for the 90° bend manhole are presented in Table X.

Monitoring the flow rate and the flow depth at locations 1, 2 and 3 as shown on Figure 31 provides the information required to determine the head loss across the manhole. For all three manhole geometries the general energy equation may be written as:

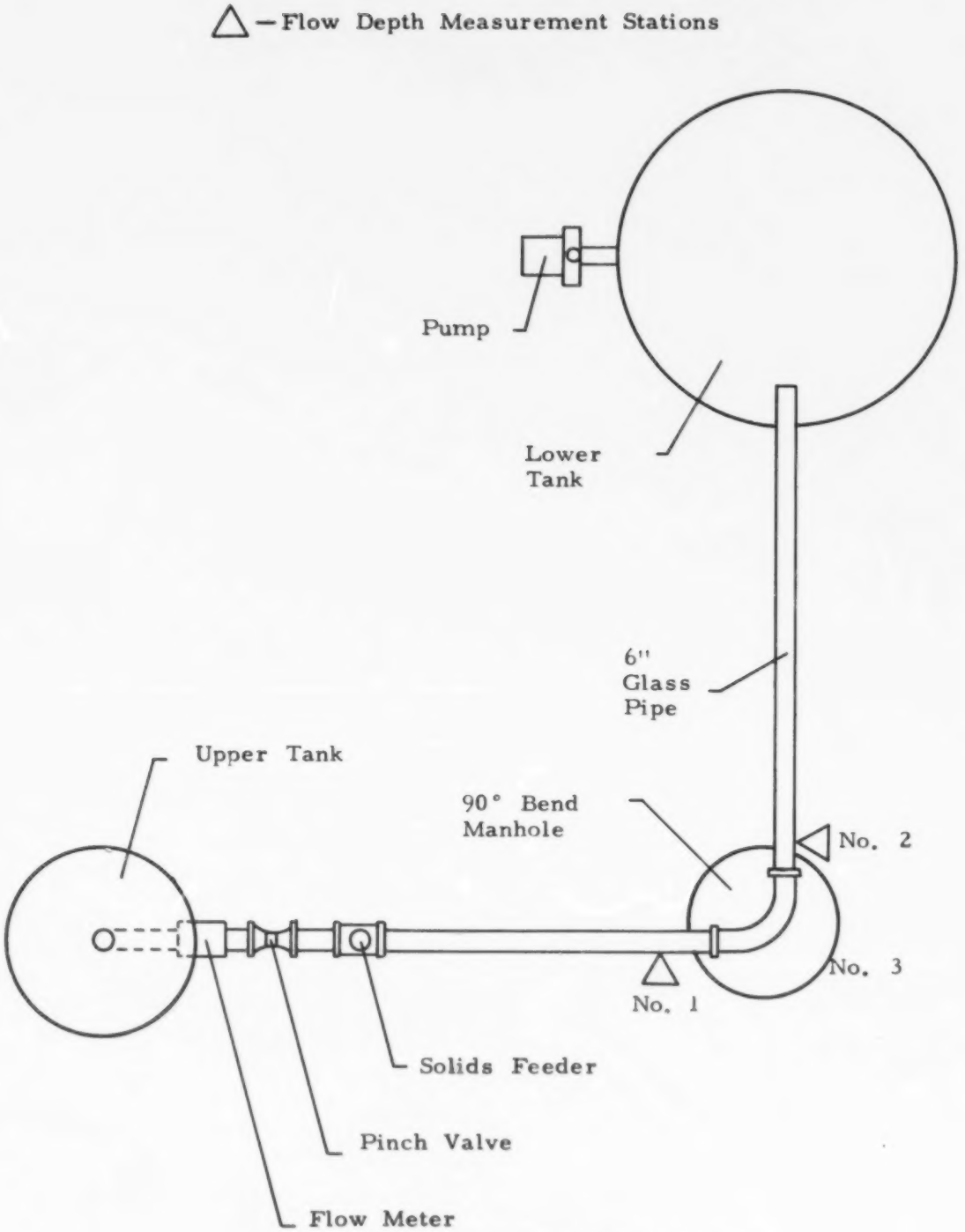
$$\frac{V_1^2}{2g} + (\ell_1 s_1 + \ell_m s_m + \ell_2 s_2) + d_1 = \frac{V_2^2}{2g} + d_2 + H_L \qquad (4)$$

with variables defined on Figure 36.



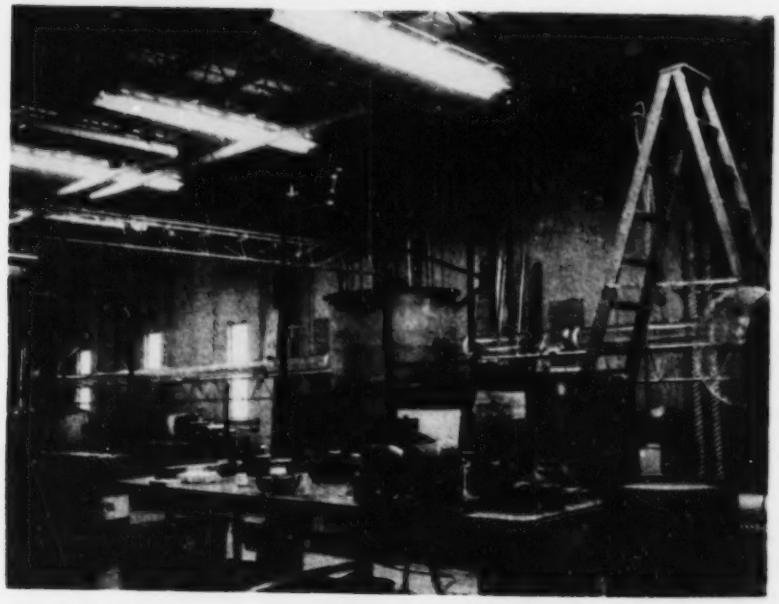
Flow Loop for Straight Manhole Tests

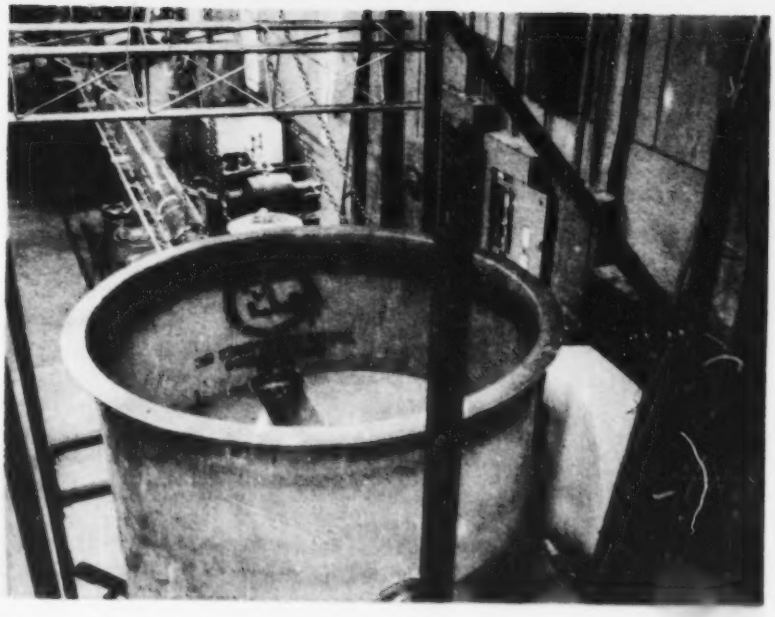
Figure 31



Flow Loop for 90° Bend Manhole Tests

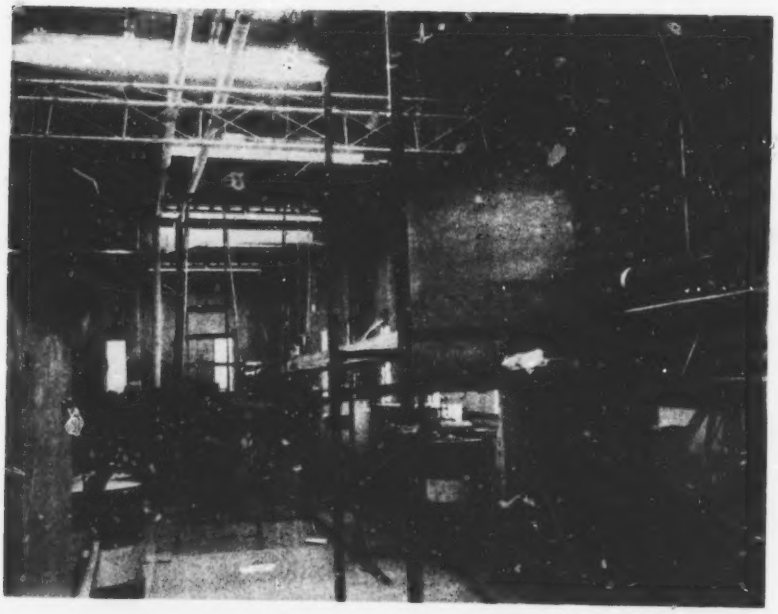
Figure 32





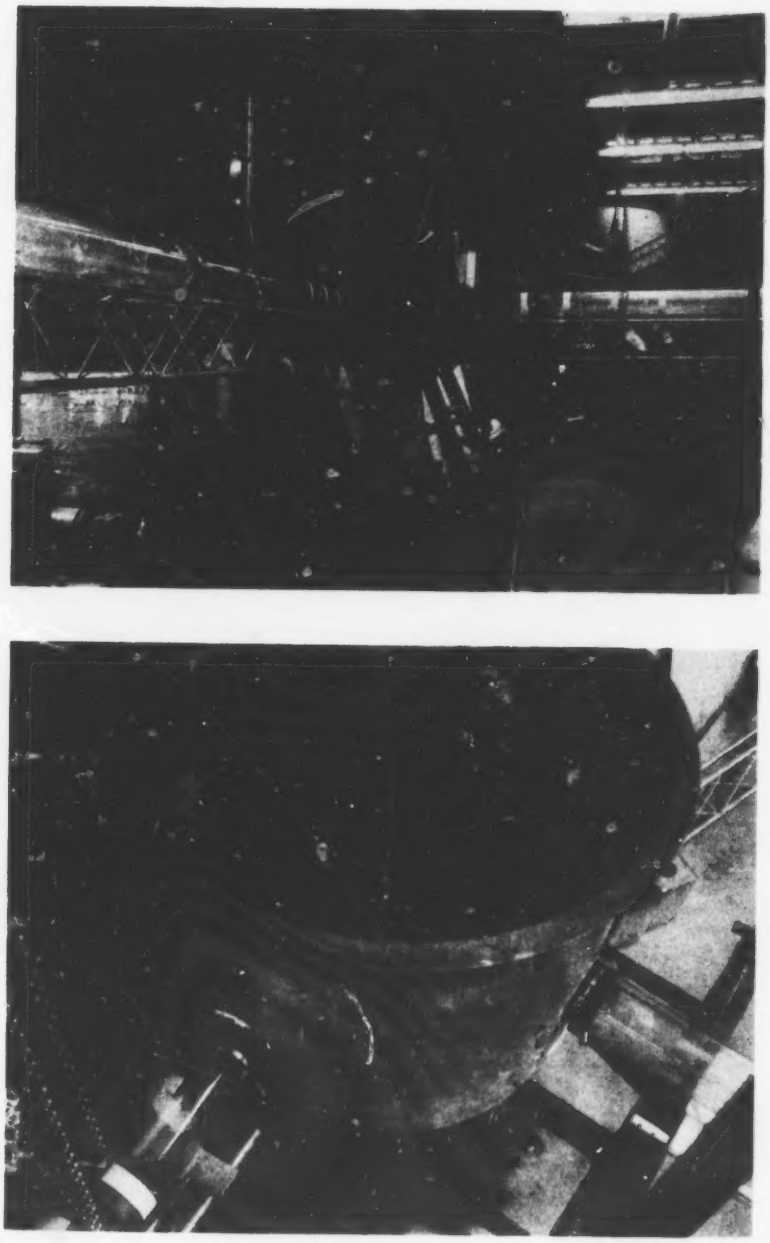
Straight Channel Manhole Model

Figure 33



Size Transition Manhole Model

Figure 34



90° Bend Manhole Model

Figure 35

TABLE IX

SLOPE COMBINATIONS FOR STRAIGHT CHANNEL AND SIZE TRANSITION CHANNEL TESTS

Outlet Pipe Slope	Inlet Pipe Slope
0.002	0.002 0.004 0.006 0.008 0.010
0.006	0.006 0.008 0.010
0.010	0.010 0.012

TABLE X

SLOPE COMBINATIONS FOR 90° BEND MANHOLE TESTS

Outlet Pipe Slope	Inlet Pipe Slope
0.002	0.002 .006 .010
0.006	.006 .010
0.010	.010 .012

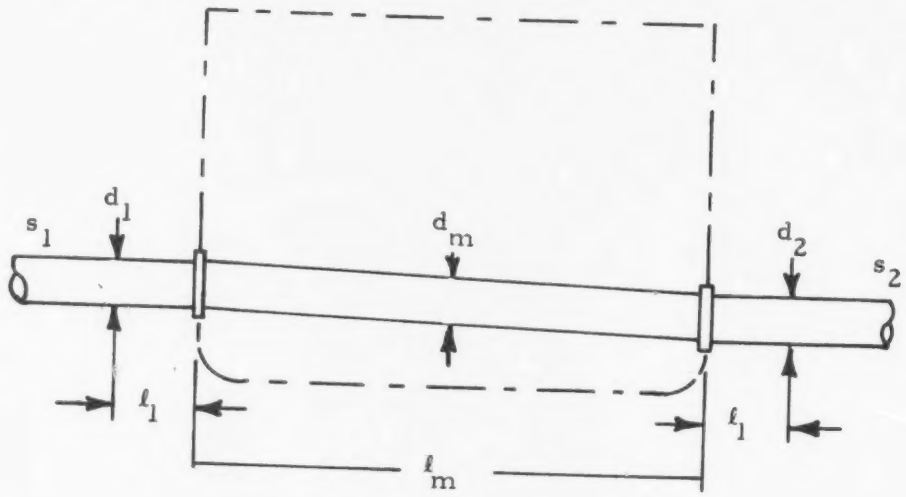
s_1 - slope of inlet pipe

s_2 - slope of outlet pipe

s_m - slope of manhole

d_1, d_2, d_m - depth of flow in inlet pipe, outlet pipe and manhole

ℓ - length of elements



Definition of Manhole Geometry Symbols

Figure 36

Thus, head loss may be defined as

$$H_L = \frac{1}{2g} (V_1^2 - V_2^2) + (h_1 - h_2) + (s_1 \ell_1 + s_2 \ell_2 + s_m \ell_m)$$

The values of the parameters of course vary for the three manhole geometries.

Expressing head loss in terms of the inlet velocity head and a loss coefficient, we have

$$H_L = k_m \frac{V_1^2}{2g} \qquad (5)$$

The head loss experiments determined values for the loss coefficient for each manhole geometry at several ground refuse concentrations.

The procedure employed to determine the scouring velocities was similar to that employed with other configurations. EPA heavy solids were used and fed into the inlet at a constant rate. The flow rate and the slopes of the inlet and outlet pipes were varied over a wide range with the slope of the manhole fixed at 0.025.

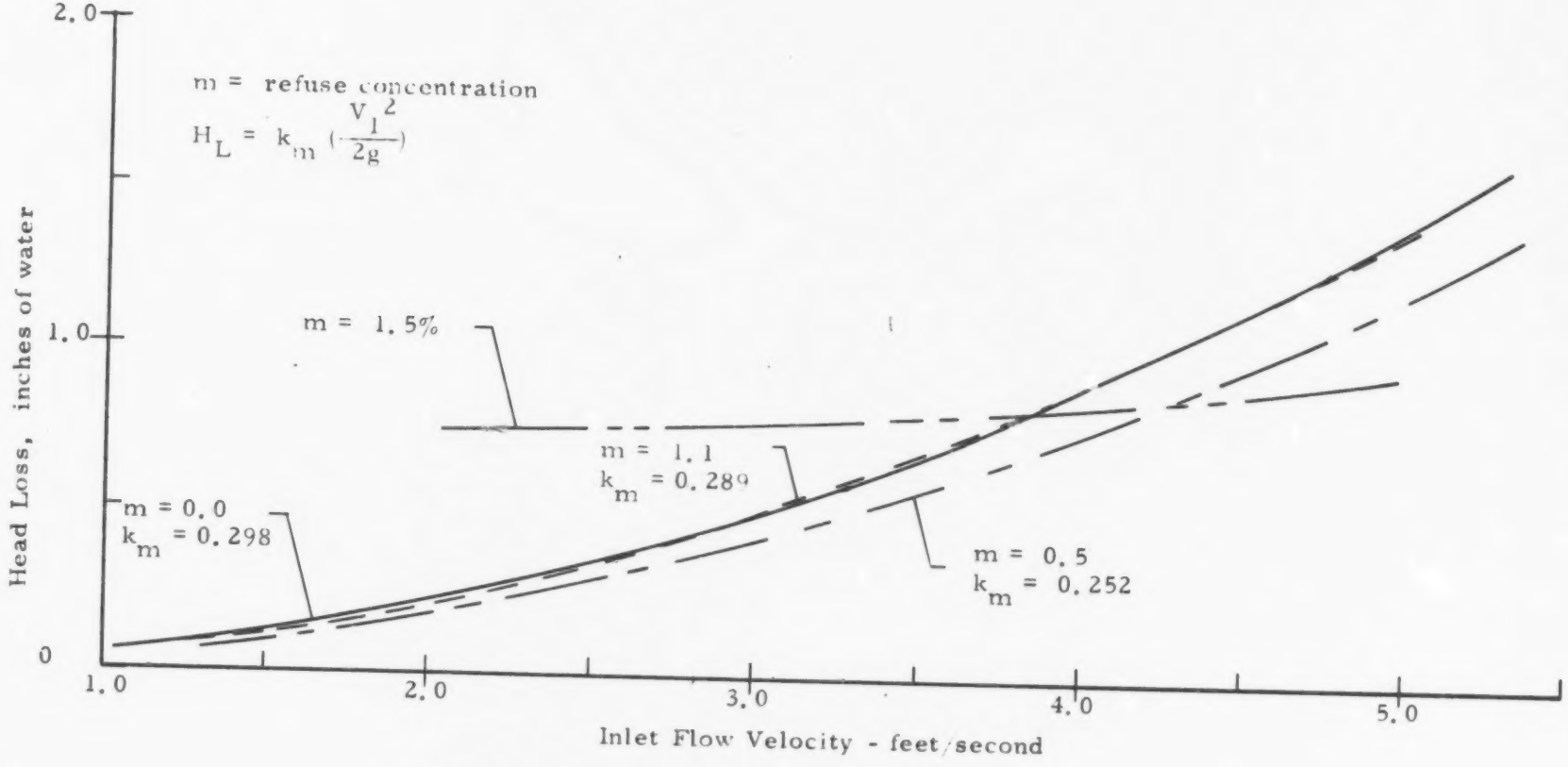
Experimental Head Loss Results

The measured values of volumetric flow rate and flow depth were used to compute the flow velocity, head loss and head loss coefficient based on Equations 4 and 5. The detailed data is presented in Figures A-4 through A-15 of Appendix A and summarized on Figures 37, 38 and 39 using the average head loss coefficients. The data shows general trends in the head loss characteristics for the several refuse concentrations. Reference to Figures A-4 through A-15 indicate the amount of scatter in the data. This was due to transient behavior of the flow and standing waves which developed at various positions in the pipe.

Figure 37 portrays the head loss at 1.5 percent refuse concentration as a relatively constant value independent of flow velocity. The head loss for this case is higher than expected at low velocity and low for high velocities. At velocities greater than 4 feet per second, the head loss at 1.5 percent refuse is lower than for clear water. Figure A-7 presents the data leading to this curve.

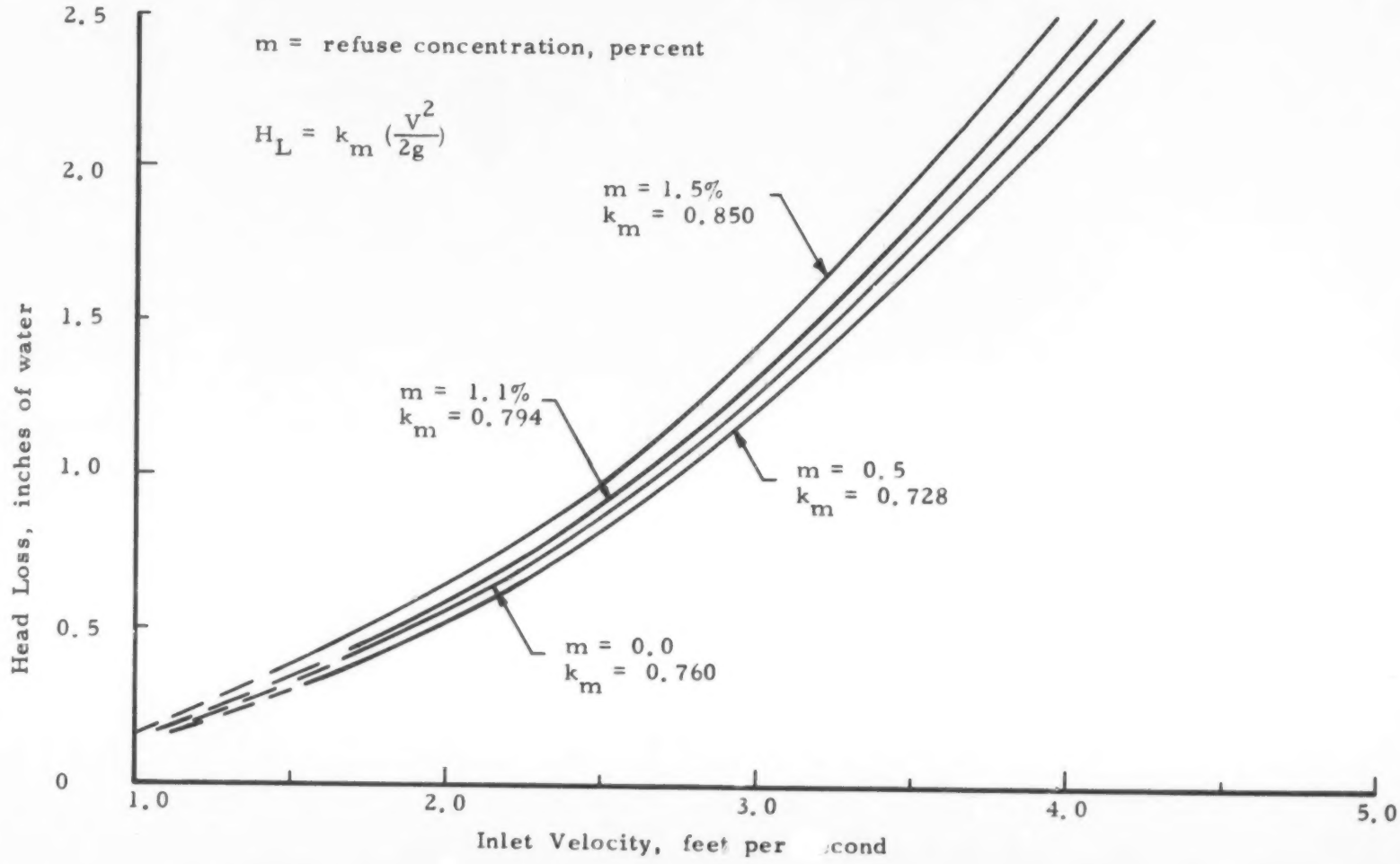
Data collected for the 90° bend manhole led to the more usual curves presented in Figure 38.

The size transition manhole yielded data with considerable scatter as shown in Figure A-12 through A-15. Except for the clear water case, the data exhibited peculiar behavior. At low velocities, the head loss approached a constant



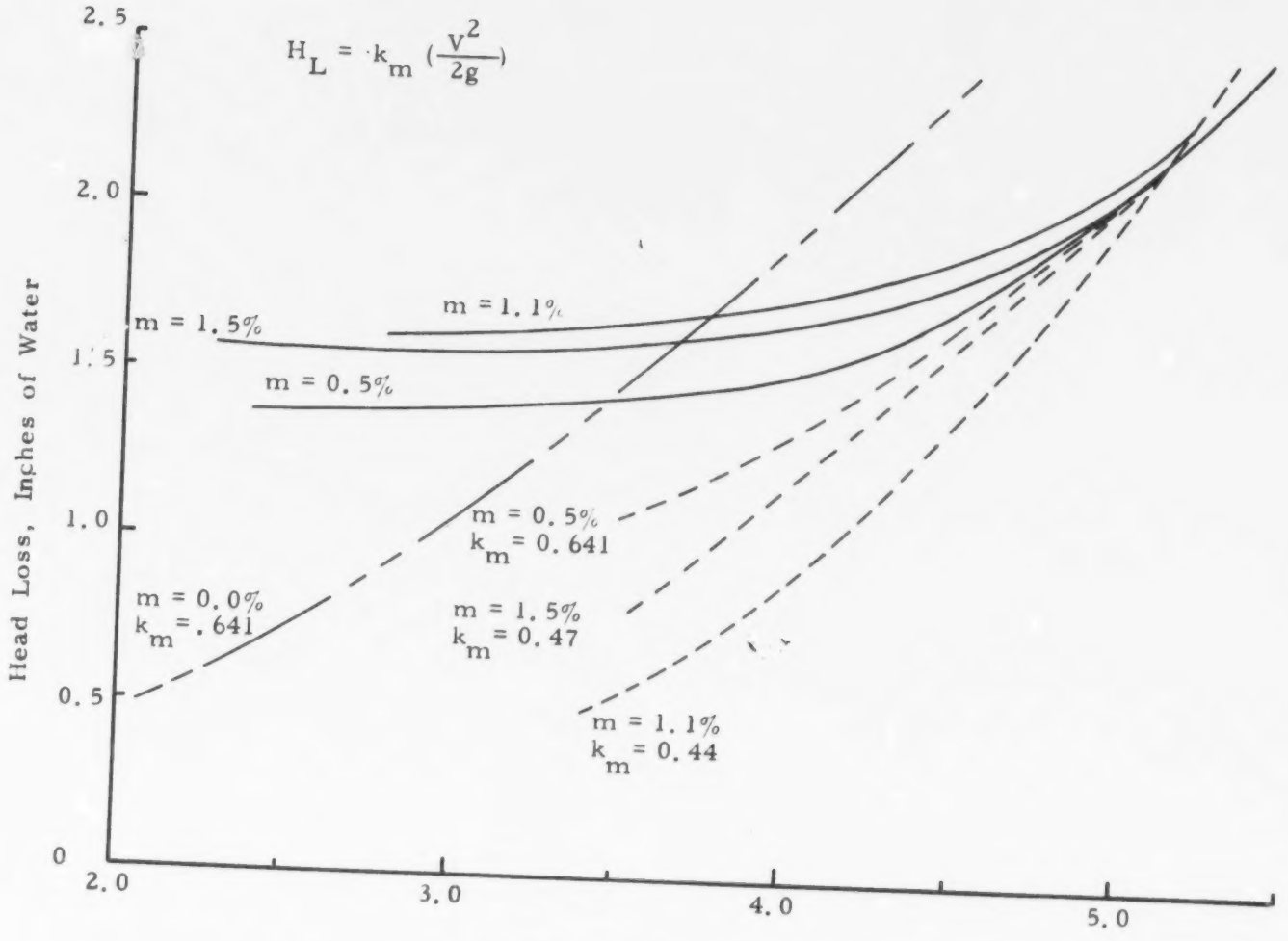
Head Loss Characteristics for Straight Manhole

Figure 37



Head Loss Characteristics for 90° Bend Manhole

Figure 38



Head Loss Characteristics for Size Transition Manhole

Figure 39

TABLE XI

AVERAGE HEAD LOSS COEFFICIENTS FOR MANHOLE FLOWS

Refuse Concentration	Head Loss Coefficient k_m		
	Straight Channel	Size Transition	90° Bend
0.0	0.298	0.641	0.760
0.5	0.252	0.51	0.794
1.0	0.289	0.44	0.728
1.5	---	0.47	0.850

value considerably higher than predicted by the higher velocity data. At higher velocities, the head loss was proportional to the kinetic energy of the flow. The broken line in Figures A-13 through A-15 is based on the head loss coefficient calculated based on the higher velocity data. The solid line reflects the mean value of the lower velocity data. No explanation is available for this unusual behavior.

The average values of head loss coefficient are presented in Table XI for all three manhole configurations. Several general conclusions may be drawn from the data presented in Figures 37, 38 and 39 in conjunction with Table XI.

(1) For the straight manhole and the 90° bend manhole the head loss is proportional to the kinetic energy at the inlet over the entire range of flows at refuse concentrations up to and including 1.1 percent. At the 1.5 percent level the losses are relatively constant for the lower range of velocities.

(2) For the size transition manhole the losses are proportional to the inlet velocity only at the higher velocities. At lower inlet velocities the head loss approaches a constant value for all values of refuse concentration.

(3) For inlet velocities less than 5 feet per second and all refuse concentrations, the head losses were:

   (a) less than 1.5 inches of water for the straight channel

   (b) less than 2.5 inches of water for the size transition

(4) The effect of refuse concentration on head loss through manholes of these types is not significant except for very low inlet velocities and refuse concentrations in excess of 1.1 percent.

The trends in the head loss data for the size transition manhole presented in Figure 39 are significantly different from those of most other appurtenances. The clear water test data in Figure 39 demonstrates a head loss proportional to inlet kinetic energy over the full velocity range. For flows containing ground refuse, however, this proportionality holds only for inlet velocities of 5 feet per second and above. As shown in Figures A-13 through A-15 a transition occurs in the 4-5 feet per second velocity range while at lower velocities the head loss becomes relatively independent of velocity. This effect is shown very clearly on Figure 39 where the data has

been summarized and curves drawn based on average values. The broken curves demonstrate extrapolation of the curves based on the coefficients determined by the higher velocity data points. The actual losses are higher than the predicted values in the low velocity range.

Experimental Scouring Velocity Results

For all manhole configurations tested, the critical region in terms of solids accumulation is not in the channel of the manhole but rather in the outlet pipe just downstream of the manhole. Within the manhole the high slope of the channel produces flow velocities considerably higher than those in the pipes. At the manhole outlet, however the slope of the channel changes from 0.025 to the 0.002 to 0.010 of the outlet pipe. At this slope, discontinuity the high velocity decays in a hydraulic jump and the suspended heavy solids settle out. The solids accumulate in the section of straight pipe just beyond the manhole outlet.

The scouring process in this region for the partial flow condition is somewhat complex. The heavy solids are deposited in a pile immediately downstream of the hydraulic jump in the low velocity flow region. Scouring at the pile occurs only when the free stream velocities are quite high as shown in Table XII.

Unlike the full flow situation the blockage in this case does not restrict the area available for flow and thus produce local high velocity which aids in scouring of the solids. For the manhole situation with partial flow the solids accumulate in a region characterized by low velocity flow. The accumulation changes the location of the hydraulic jump but does not affect the velocity downstream of the jump.

At steady state the solids pile extends downstream to the point where the flow velocity has reached that level required for scouring in a straight pipe. After steady state is reached the heavy solids are added and removed from the pile at the same rate.

The quantitative scouring velocity results presented in Table XII include the inlet velocities required to scour the solids which accumulate downstream of the manhole. Where applicable the velocities required to scour solids in the inlet pipe are also presented.

The scouring velocities of Table XII are quite high because they represent the velocity required upstream of a hydraulic jump to scour heavy solids located downstream of that jump.

The accumulation of solids during low flow periods will produce minor head loss locally in the system but there is no indication that accumulation will continue to the point where flow is restricted significantly. It appears likely that accumulations of a similar nature occur in present sewer systems with no adverse effects.

TABLE XII

MANHOLE SCOURING VELOCITY SUMMARY

Type of Manhole	Solids		Refuse Concentration Percent	Pipe Slope		Scouring Velocity, ft/sec			
						Inlet Pipe		Outlet Pipe	
	Type	Rate		Inlet	Outlet	Initial	Clean Out	Initial	Clean Out
Straight Thru	EPA	5	0	$6x10^{-3}$	$6x10^{-3}$		2.9	3.9	4.6
				4	4		3.0	4.3	4
				2	2	2.3	2.8		
			1.0	2	2	2.3	2.8		
				4	4	2.3	2.8	2.9	3.4
				6	6		1.7	4.8	5.6
	Sand & Glass	10	0	4	4	2.8	2.9	3.3	4.0
			1.0	4	4			3.9	4.5
Size Transition	EPA	5	0	2	2	3.05	3.05		
				2	6			4.6	4.6
				6	6		2.5	4.0	4.6
				4	4	2.3	2.6	3.1	3.6
				12	6	1.5	2.9		
			1.0	8	6	3.05	3.05	4.5	4.6
	Sand & Glass	10	0	12	6	3.05	3.1	3.7	3.9
90° Bend	EPA	5	1.0	10	10		4.3		3.85

CHAPTER 7

PIPE JUNCTION FLOW EVALUATION

On small sewers, junctions are normally made in manholes, the branch line being curved in to the main channel. Large junctions generally are constructed in cast-in-place, reinforced concrete chambers. The only junction flows which occur commonly in pipes in sewer systems occur where the sewer line from a building ties into the street sewer. These are identified as house connections, service connections or service laterals.

These service laterals are usually 4, 5 or 6 inches in diameter and frequently have a slope of 0.020. Wyes or tees are used to connect the service laterals to the street sewer line. The tees produce a somewhat less desirable flow situation and are more susceptible to solids accumulation and clogging than are the wyes. For this reason the tee configuration was selected for the junction flow test program.

The flow of ground refuse through a tee connection was investigated in the laboratory to study the effect of flow interference at junctions on energy loss and solids deposition.

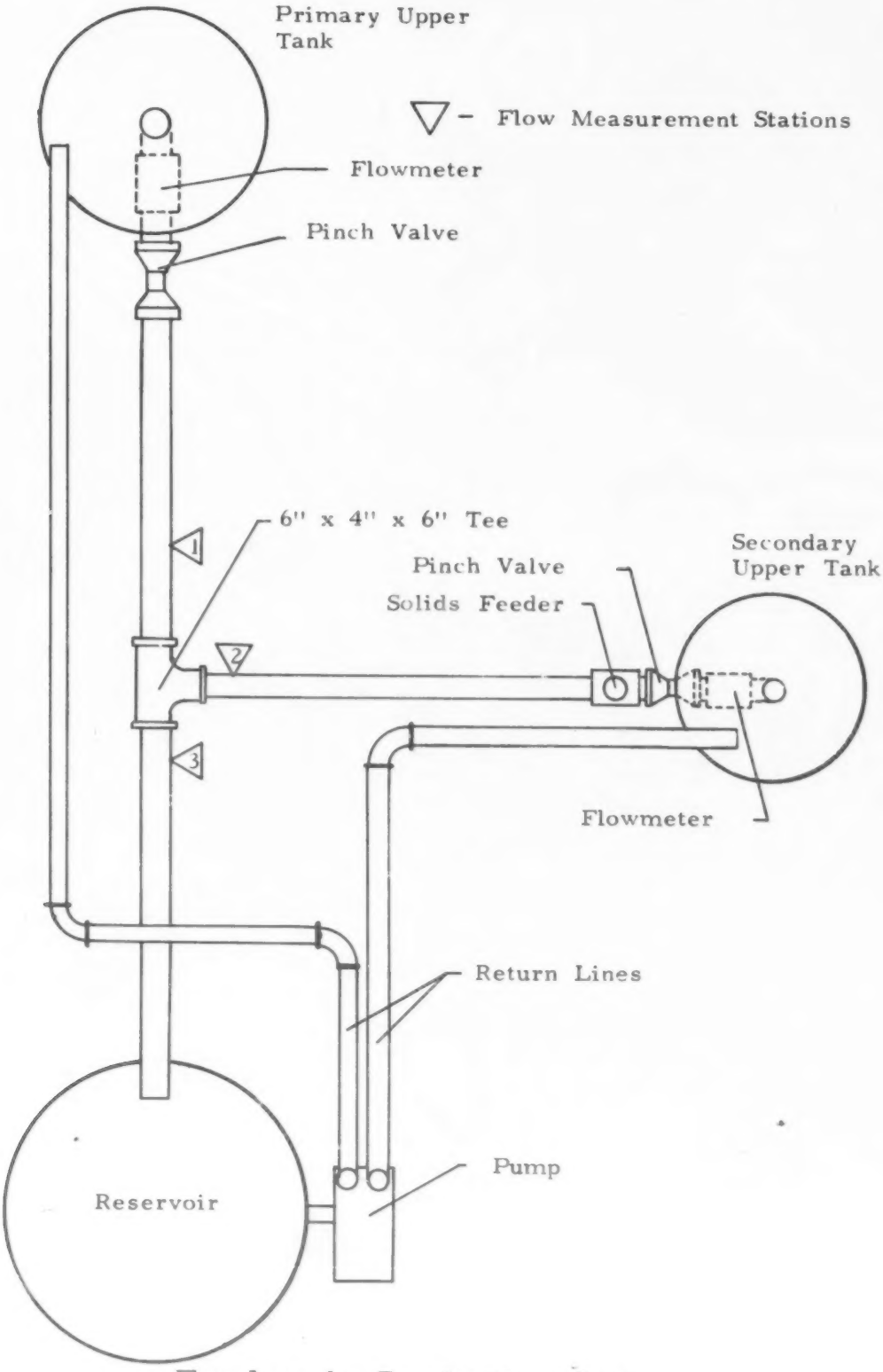
Experimental Facility and Test Procedure

The experimental facility employed to evaluate head loss and scouring characteristics in junction flow is shown schematically in Figure 40. Two supply tanks are used to provide independent sources for the 6" main line and the 4" service lateral. The slope of the main line and the service lateral are independently adjustable. For our testing the service lateral was pitched at 0.010 to 0.020 while the slope of the main was held between 0.002 and 0.010.

The heavy solids feeder was mounted to feed the lateral to simulate the potentially high concentration of heavy solids likely to be generated in a residence.

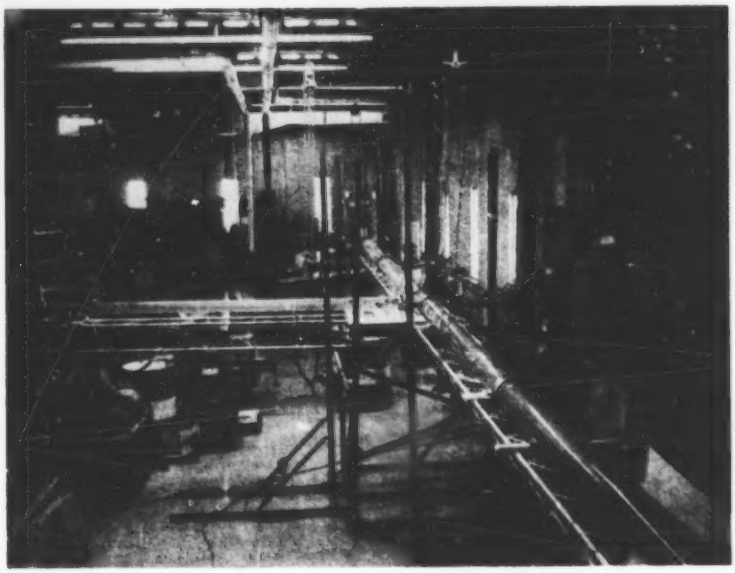
Flow meters were installed in both the main line and the lateral to permit simultaneous monitoring of both flows. Three flow depth measurement stations were located upstream in each leg and three downstream of the tee at distances of 2, 3 and 4 feet from the center of the junction.

A photograph of the junction flow facility is presented in Figure 41a. Figure 41b presents a more detailed view of the tee section with the measurement stations indicated.

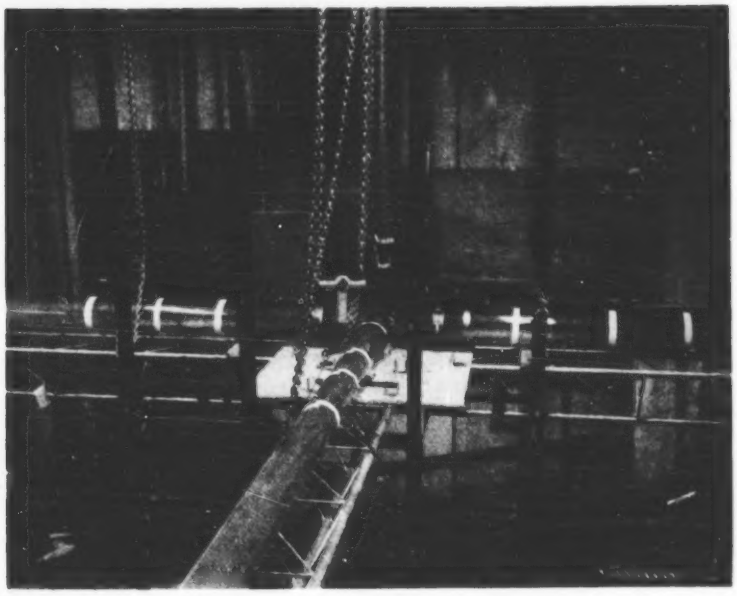


Flow Loop for Tee Junction Tests

Figure 40



(a) Junction Flow Test Facility



(b) Detailed View of Tee

Junction Flow Test Facility

Figure 41

The test procedure for the evaluation of junction flow characteristics was somewhat more elaborate than the tests previously discussed. With the slopes of the main line and the "service lateral" independently adjustable and the two flow rates also independently adjustable, the number of possible test conditions increased tremendously. Data taken during the testing included:

(a) slope of main and lateral

(b) flow rate in main and lateral

(c) flow depth in the 6" and 4" inlet pipes

(d) flow depth in the 6" outlet.

This information may be applied to the energy equations to determine the head loss across the junction.

For the junction configuration the energy equation may be written:

$$E_1 + E_2 = E_3 + H_L$$

$$w_1 \left(\frac{V_1^2}{2g}\right) + s_3 \ell_3 + s_1 \ell_1 + d_1 + w_2 \left(\frac{V_2^2}{2g}\right) + s_3 \ell_3 + s_2 \ell_2 + d_2 =$$

$$(w_1 + w_2) \left(\frac{V_3^2}{2g}\right) + d_3 + H_L \qquad (6)$$

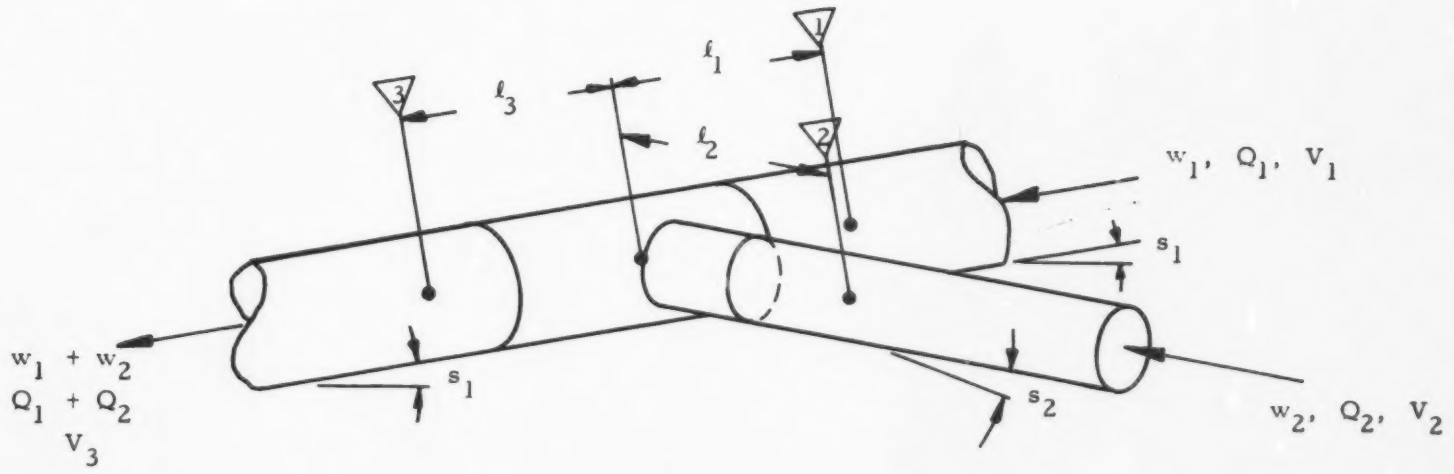
or

$$H_L = \frac{Q_1}{Q_1+Q_2} \left(\frac{V_1^2}{2g}\right) + s_3 \ell_3 + s_1 \ell_1 + d_1$$

$$\frac{Q_2}{Q_1+Q_2} \left(\frac{V_3^2}{2g}\right) + s_3 \ell_3 + s_2 \ell_2 + d_2 - \frac{V_3^2}{2g} - d_3 \qquad (7)$$

with variables as defined on Figure 42.

The two flow rates were set simultaneously using the Fischer and Porter flowmeters. The three critical flow depths were then read. This provided the data required for determination of the head loss in the tee.



w_n = mass flow at n
Q_n = volumetric flow at n
V_n = velocity at n
d_n = depth at n
s_n = pipe slope at n
ℓ_n = distance from intersection to station n

Nomenclature for Energy Balance in Junction

Figure 42

To determine the scouring characteristics of the branch flow situation a series of tests were run in which heavy concentrations of solids were fed into either the 6" main or the 4" lateral. Tests included a wide range of flows in both the 6" main and the lateral. Some tests were run with no flow into the main line. In all cases, for the scouring velocity tests the slope of the main and lateral were 0.010 and 0.020 respectively.

Experimental Head Loss Results

The data gathered during the junction flow test program was used to establish average head loss coefficients based on the velocity in the 4" lateral. This data is summarized in Figure 43 for each of the four refuse concentrations tested. From these curves the effect of increased concentration of refuse may be determined.

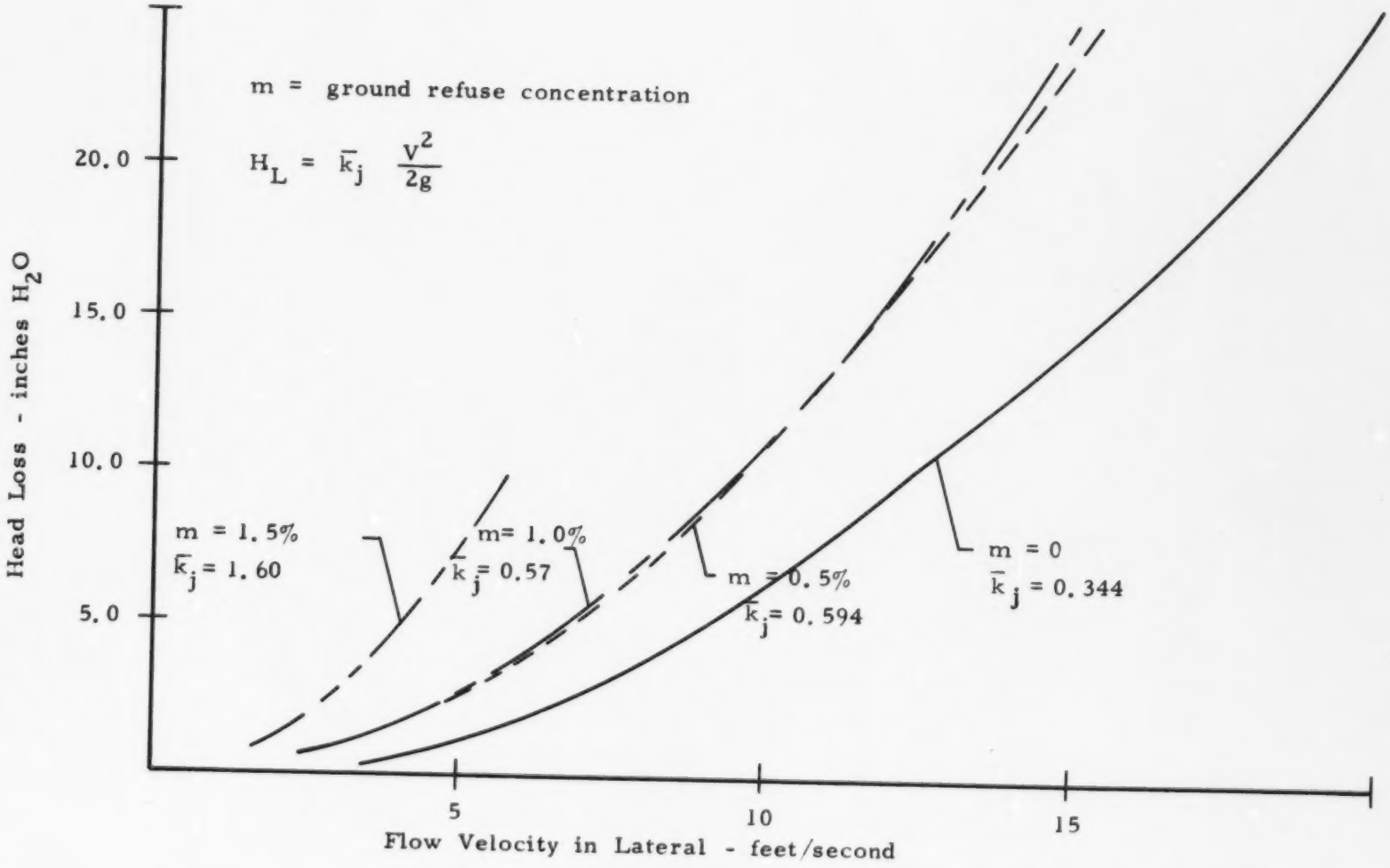
The head loss at the junction is influenced by variables other than the velocity in the lateral. These include the velocity in the main and the ratio of the volumetric flow in the main and lateral. The influence of these other factors was reflected in the scatter evident in the data. In spite of the scatter the trends in the data were evident. The average head loss coefficients shown by the curves do provide a means for quantitative comparison of the performance of several refuse concentrations. These coefficients are summarized in Table XIII.

The results indicate that for the junction tee as for most sewer appurtenances the effect of ground refuse on the head loss was not significant until the 1.0 percent concentration had been exceeded.

Scouring Velocity Tests

Determination of the scouring velocity in the vicinity of the tee is complicated by the possibility of backflow into either the main or the lateral from the line carrying the bulk of the volumetric flow. Four specific flow situations were investigated to determine scouring characteristics for a wide range of flow conditions.

(1) fixed moderate flow in lateral;
range of flows in main line;
heavy solids fed into main;
no refuse other than heavy solids



Tee Junction Head Loss Results

Figure 43

TABLE XIII

HEAD LOSS COEFFICIENT FOR TEE

Refuse Concentration	Head Loss Coeffieient $k_j = H_L \left(\frac{2g}{V^2}\right)$
0.0	.344
0.5	.594
1.0	.570
1.5	1.597

(2) same as above with 1.0 percent refuse in flows in both lines

(3) zero flow in main; range of flows in lateral; heavy solids added into lateral; no refuse other than heavy solids

(4) same as (3) with 1.0 percent refuse in flow.

In general the effect of the flow entering the main stream through a lateral is to locally reduce the velocity of the main stream and thus encourage deposition of the heavy solids just upstream of the junction. Increased velocities are required in the main during periods of appreciable flows from the lateral to insure that the heavy solids will carry through the junction. In general, a velocity of approximately 4.5 feet per second was required upstream of the junction to carry the heavy solids through the junction and downstream. This velocity was independent of the refuse concentration in the flow.

After the flow through the lateral and the consequent interference with the flow in the main has ceased the accumulated solids are quickly scoured. Flow velocities required for this scouring are identical to those required for straight pipes - on the order of 2.5 feet per second. This is extremely important in evaluating junction flow patterns. Flows from service laterals are typically sporadic. The lateral flow will occur in batches followed by periods of no flow. For this reason the 4.5 feet per second velocity required for scouring is not critical. The design flow velocity will adequately scour the deposits during periods of no lateral flow.

In situations where the main flow is negligible, the flow from the lateral washes into the upstream leg of the junction and deposits solids in the main. The larger diameter of the main and its reduced slope result in deposits of heavy solids in the main downstream of the junction as well. This occurs even for relatively high velocities in the lateral. The deposits both upstream and downstream of the junction are effectively scoured when the velocity in the main reaches 2.5 feet per second.

Quantitative scouring velocity data is presented in Table XIV that reflects the above conclusions. The scouring velocity refers to the flow velocity measured in the leg with the variable flow. The last two entries in the table - for zero lateral flow - indicate the velocity required to scour heavy solids deposited by lateral flow during periods of low main flow.

TABLE XIV

SUMMARY OF JUNCTION TEE SCOURING DATA

Refuse Conc. in Flow	Type of Solids	Where Added		Flow Velocity -fps.		Slope		Feeding Rate	Scouring Velocity*	
		Main	Lateral	Main	Lateral	Main	Lateral		Initial	Clean Out
0%	EPA	X		Vari.	1.8	0.010	0.020	5 lb/min	3.3	4.6
0%	"		X	0	Vari.	0.010	0.020	5 lb/min	3.1	4.4
1.0%	"	X		Vari.	1.8	0.010	0.020	5 lb/min	3.6	4.5
1.0%	"		X	0	Vari.	0.010	0.020	5 lb/min		4.0
0%	"	X		Vari.	0	0.010	0.020	0	2.3	2.6
1.0%	"	X		Vari	0	0.010	0.020	0	2.2	2.6

* Scouring Velocity Measured in Leg with Variable Flow.

Because of the sporadic nature of the lateral flow and the relatively low scouring velocity in the main for situations with no lateral flow, the tee junction presents no major problems with regard to ground refuse transport. The more satisfactory hydraulic behavior in wye junctions insures satisfactory performance for those as well.

CHAPTER 8

PUMP INLET FLOW EVALUATION

Satisfactory flow characteristics through pump inlets with the ground refuse slurry are essential if hydraulic transport of ground refuse through the sewer system is to be feasible. Two potential problems exist at the pump inlet with the ground refuse slurry:

(1) for high refuse concentrations the inlet may tend to plug with the more coarsely ground or stringy materials.

(2) heavy solids may not be satisfactorily scoured into the pump and may accumulate at the inlet restricting the flow.

To investigate these phenomena a model pump inlet was fabricated in the FMA laboratory and installed in the hydraulic flow loop.

Experimental Facility and Preparation

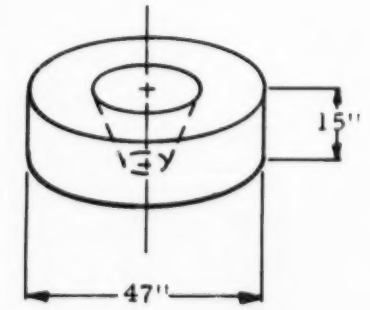
A typical pump inlet configuration was selected from Reference 4 and fabricated from rigid urethane foam in a manner similar to that described for the manhole benches and channels in Chapter 6. Sketches of the wet well are presented in Figure 44.

The wet well insert of Figure 44 was placed inside a fiberglass tank four feet in diameter which contained the water above the insert. The fiberglass tank and the rigid foam insert were then placed inside the lower reservoir of the FMA flow loop with the pump inlet pipe in the position shown in Figure 45. The return flow was directed into the top of the fiberglass tank but overflow into the large reservoir was permitted. Photographs of the installation are presented in Figure 46.

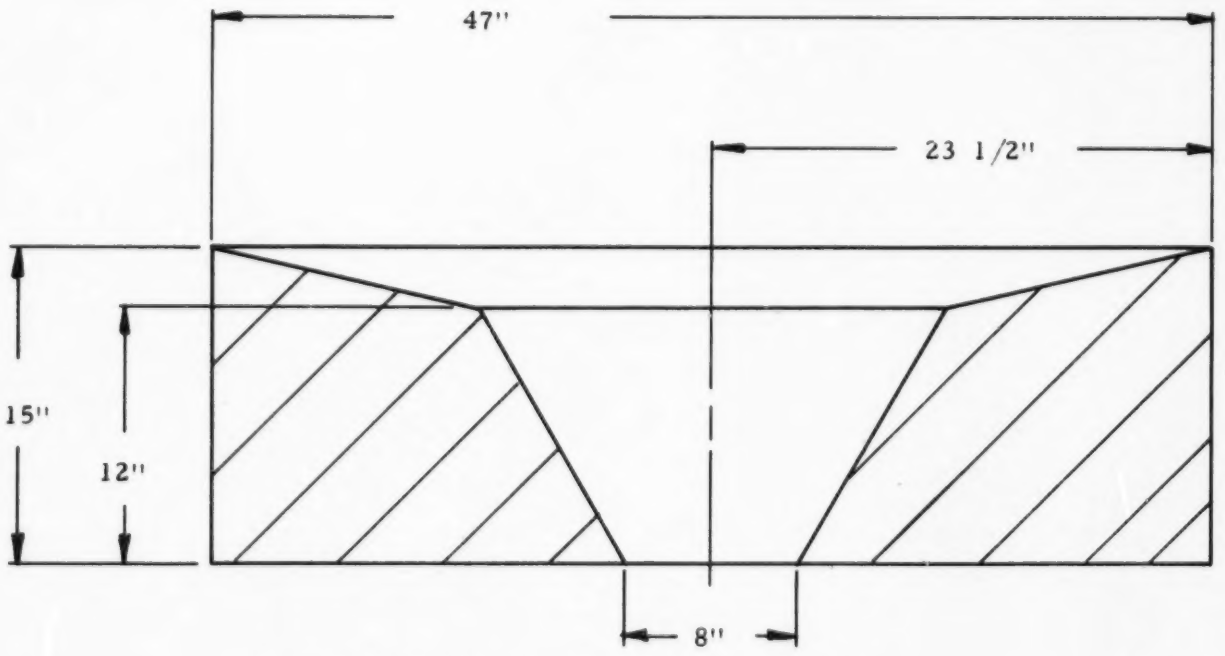
The use of an inexpensive, light weight foam in place of concrete to simulate the pump suction inlet provides many advantages in terms of ease of handling, fabrication and removal.

Experimental Procedures

Quantitative determination of the flow characteristics in the vicinity of the pump inlet is not practical without elaborate instrumentation. Rather than attempt to establish pressure drop characteristics for the pump inlet over the range of refuse concentrations of interest it was decided rather to insure satisfactory operation under extreme refuse concentrations and heavy solids loadings.

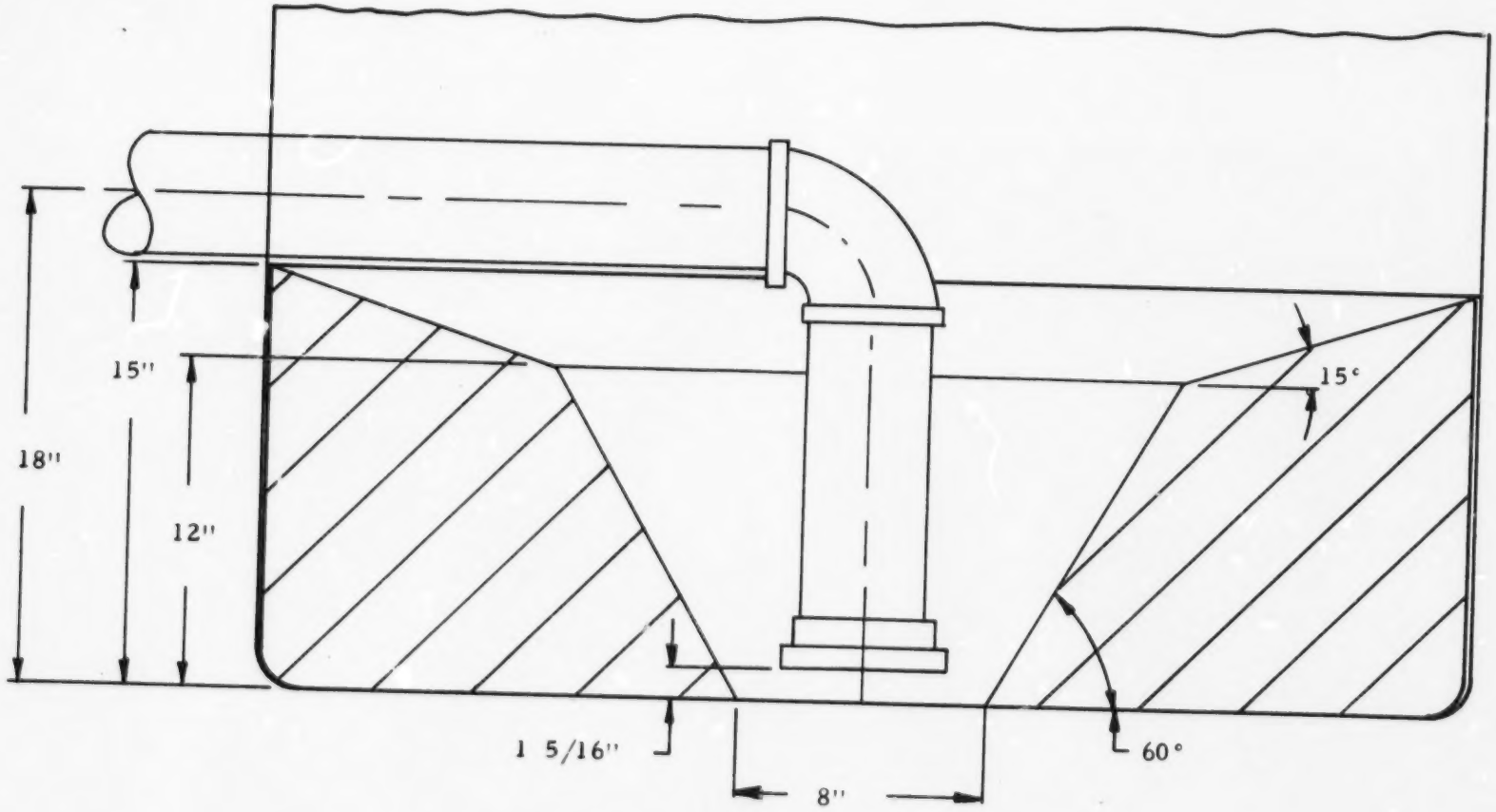


Material - Urethane Foam



Wet Well Design for Pump Inlet Tests

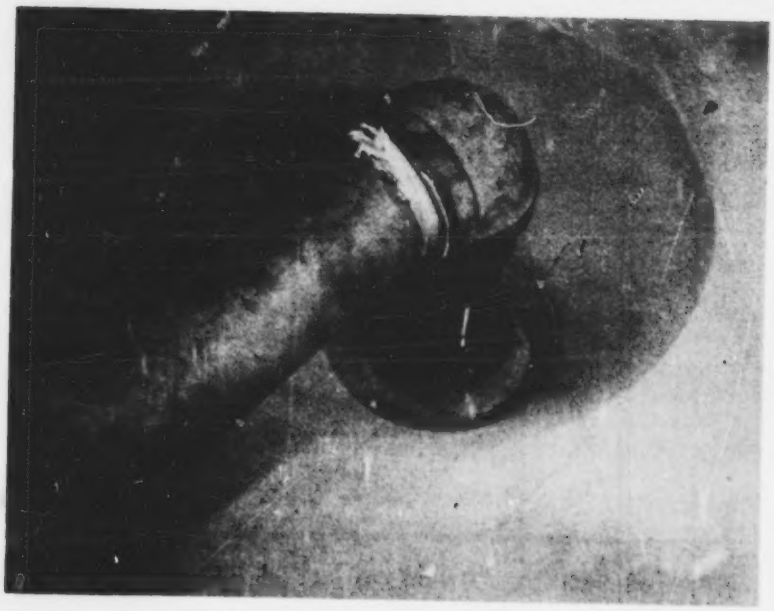
Figure 44



Pump Inlet Configuration for Flow Study

Figure 45

(a) Wet Well Insert in Fiberglass Tank



(b) Detail of Pump Inlet Design

Simulated Wet Well for Flow Facility

Figure 46

Heavy solids were fed directly into the wet well forming the pump inlet at rates of 5, 10 and 15 pounds per minute. Flows were adjusted to produce solids concentrations from zero to three percent, far exceeding the heavy solids loading normally anticipated. In addition, with the pump off, the well was blocked to a depth of several inches with an accumulation of heavy solids. When the pump was started, the water flow quickly scoured the heavy solids from the inlet and continued to function in a normal manner.

The heavy solids scouring tests were run with both clear water and 1.5 percent concentration of refuse.

To determine the effect of excessive refuse concentration on the inlet flow characteristics, the system was run for several hours at 1.5 percent concentration. Following this run the slurry was permitted to settle to the bottom of the pump inlet and additional ground refuse piled into the inlet to effectively double the concentration being pumped. Upon startup the pump cleared the refuse within a few seconds and again performed normally.

Pump Inlet Conclusions

Based on the studies described in the previous sections it may be concluded that pump inlets of a configuration similar to that shown in Figure 45 will present no hindrance to the flow of ground household refuse. It appears that the present design of the inlets to permit scouring of the foreign objects which occassionally enter the sewer system is adequate to permit continuous pumping of high concentrations of ground refuse and satisfactory scouring of the heavy solids - even after shutdowns which might be expected to produce blockages.

CHAPTER 9

FLOW EVALUATION IN STILLING BASINS, OVERFLOW WEIRS AND OBSTACLES

A stilling basin is generally used to dissipate large amount of kinetic energy associated with high velocity flow entering the basin. Appurtenances such as chute blocks, baffle piers and end sills are often installed to improve the performance of a stilling basin.

Overflow weirs and dam crests are often employed with siphon systems. These obstacles interfere with the flow and could lead to problems with solids deposition and clogging.

In addition to the above obstacles, other unintentional but rather common obstacles occur in sewer systems. Typical of these are branches or logs wedged across the flow path or rocks deposited in the flow by high velocity storm flows. Both branches and rocks could cause blockage of the flow as ground refuse accumulates on the surface.

Flow characteristics in stilling basins, over baffle piers and overflow weirs and in the vicinity of a variety of obstacles were studied qualitatively in a transparent plastic channel 10' long, 12" wide and 18" deep. The channel design permitted visualization of the flow patterns under a wide variety of conditions. Motion pictures of the flow patterns were taken for a wide range of flow rates with and without heavy concentrations of ground refuse.

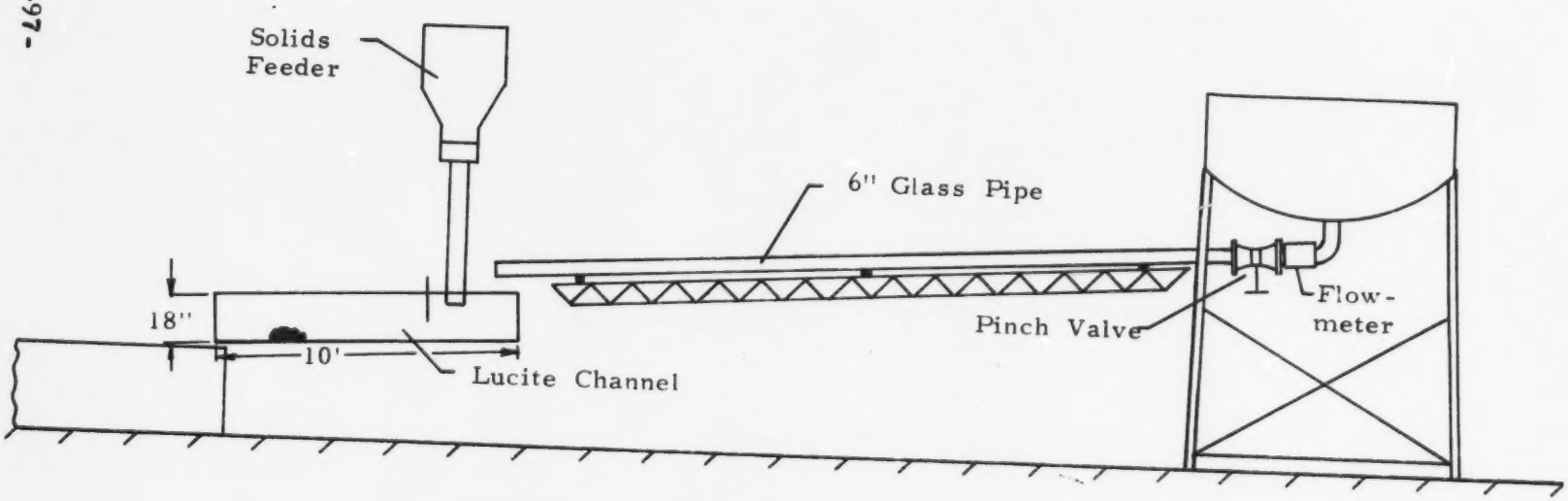
Experimental Facility and Test Procedure

The flow loop installation of the clear lucite channel is presented schematically in Figure 47. A detailed sketch of the Lucite channel is presented in Figure 48 with a photograph in Figure 49.

The inlet to the Lucite channel from the 6" glass pipe is through a flexible corrugated hose into the stilling basin section of the channel. Submerging the end of this hose forces the upstream pipe to flow full, reducing the air entrainment and turbulence in the stilling basin.

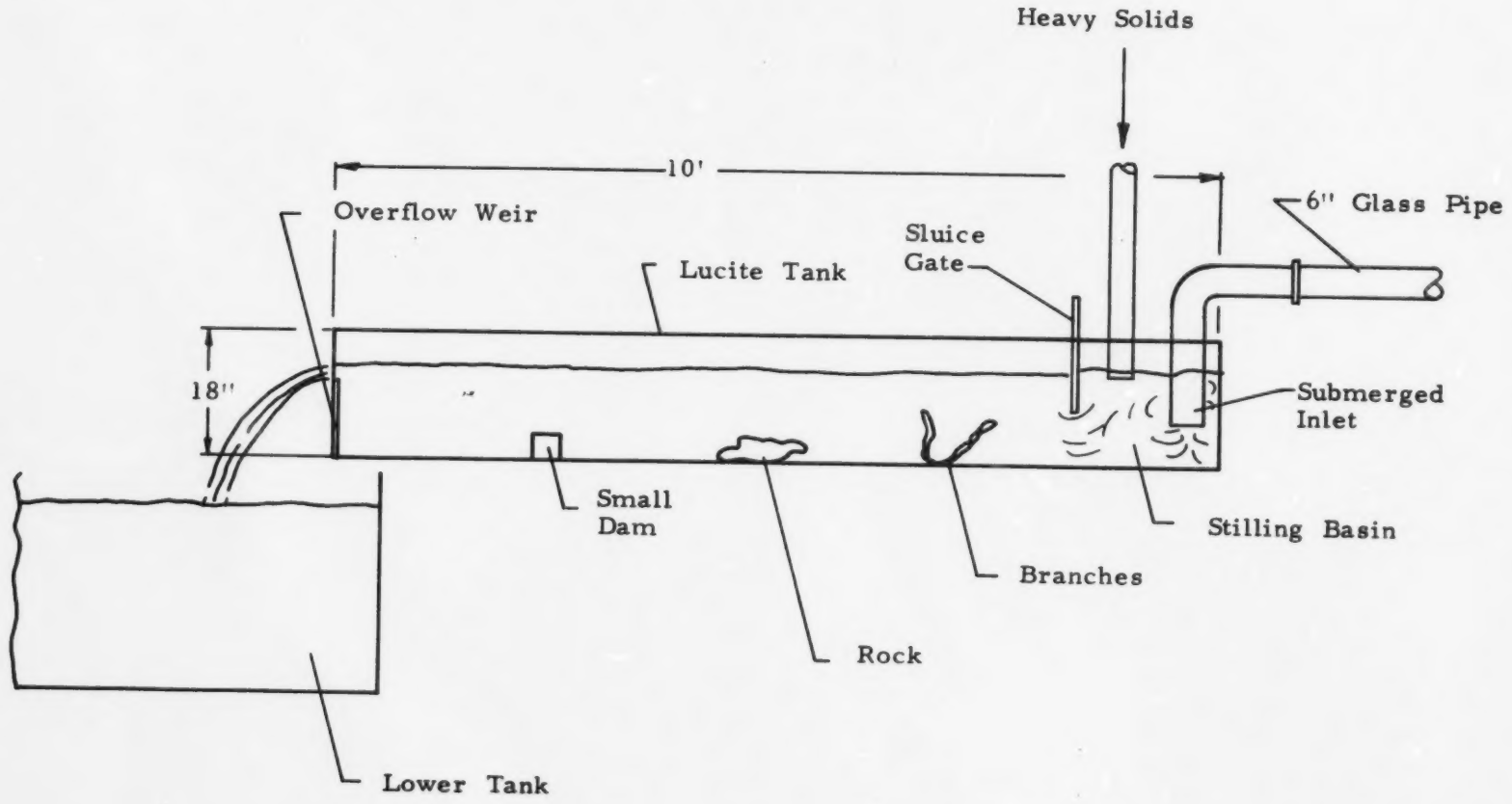
An adjustable sluice gate passes the flow from the stilling basin down the channel and - in conjunction with the throttling valve in the inlet line and the slope of the channel - allows virtually any combination of flow rate, depth and velocity.

The channel downstream of the sluice gate provides a ideal facility for investigating flow fields upstream of overflow weirs and in the vicinity of a wide variety of obstacles.



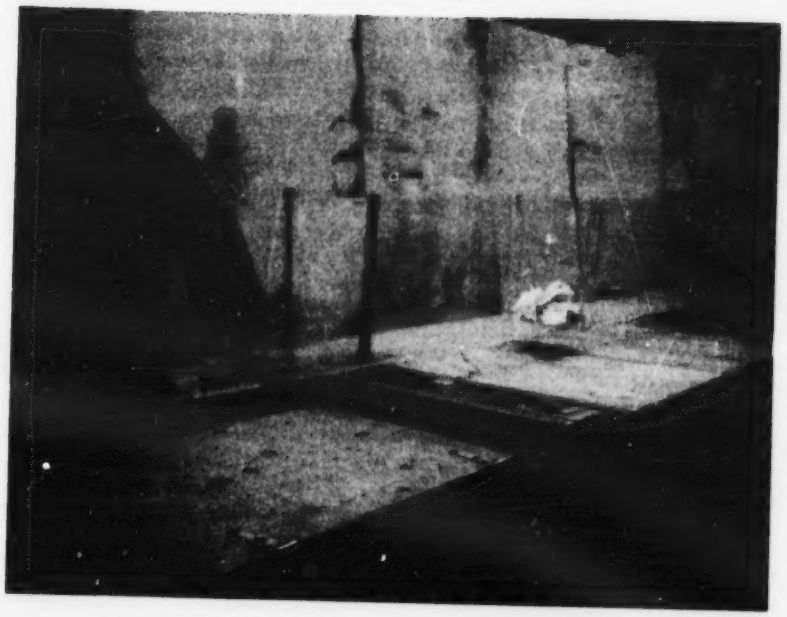
Installation of Lucite Channel in Flow Loop

Figure 47



Detail of Flow in Lucite Tank

Figure 48



Lucite Channel for Flow Visualization

Figure 49

The laboratory program for evaluating flow past obstacles included observation of the effect of ground refuse on flow fields in the vicinity of:

(1) weirs - 3", 6" and 12"

(2) sluice gates

(3) small dams

(4) branches or roots

(5) rocks

For each of these "obstacles" the studies included a wide range of flow rates, flow depths, flow velocities and refuse concentrations. Films were taken of each obstacle at various flow conditions with clear water and then in flows carrying various concentrations of ground refuse. These films provide an interesting comparison of the flow behavior with and without ground refuse.

Heavy solids were added to the flows at the inlet to the stilling basin to determine the effect of the various obstacles on heavy solids scouring.

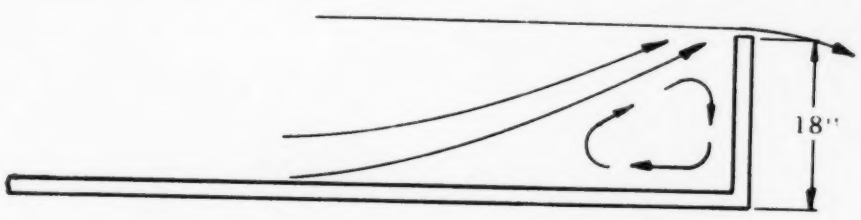
Conclusions Regarding Flow Around Obstacles

As anticipated, the flow fields in the vicinity of the obstacles tested were not significantly effected by the addition of ground refuse in concentrations up to 1.5 percent. In general the flow appeared less turbulent with less tendency to separate from solid surfaces after the refuse had been added.

Flow under the sluice gate was virtually unchanged by the addition of the ground refuse. In the small model basin tested there was no tendency for the solids to accumulate near the sluice gate or at the opposite corners of the stilling basin. In large stilling basins however it is likely that heavy solids will settle out and accumulate in the "dead" corners of these basins.

Overflow weirs of 3, 6 and 12 inch heights were tested during this program. Even with high concentrations of ground refuse there appeared to be no tendency for the refuse to accumulate at the bottom of the weir. As the refuse concentration was increased from zero to 1.5 percent the increase in the "effective viscosity" of the slurry changed the flow pattern upstream of the weirs as shown in Figure 50. This results in a stagnant region on the upstream side and directly below the outlet of the weir. Despite the apparent stagnation in this region there did not appear to be a tendency

(a) Clear Water



(b) 1.5 Percent Refuse Concentration

Variation in Flow Pattern Upstream of the Overflow Wier

Figure 50

for the suspended refuse to settle out. Heavy solids did accumulate near the outlet to the weir in this low velocity region. They did not noticeably effect the flow however and accumulated only in the low velocity region. The high velocity portion near the top of the weir satisfactorily scoured the heavy solids.

Flow over small dams or bumps was similar to that over the low weirs. The ground refuse slurry did not significantly effect the flow characteristics in the vicinity of the dam. Turbulence was reduced somewhat at the 1.5 percent concentration. Heavy solids accumulated just slightly upstream of the dam but scouring from the top of the pile prevented the accumulation from approaching the height of the dam.

Flows at many depths and velocities past the branch and rock were not effected by the addition of ground refuse up to 1.5 percent level. The refuse collected only to a slight extent on the projections at the branch and rock. Heavy solids collected briefly just downstream of the rock due to the recirculation into this region and the low fluid velocity. The heavy solids were quickly scoured away from even this region as the instabilities in the flow field led to effective scouring downstream of the obstruction.

CHAPTER 10

SUMMARY OF RESULTS AND CONCLUSIONS

Summary of Results

The principal results of this investigation are:

1. In general, for the flow velocities and refuse concentrations of interest the head losses through inverted siphons, running traps, horizontal bends, manholes and junctions are proportional to the kinetic energy of the inlet flow and may be characterized by a head loss coefficient. For the running trap, the horizontal bends and the junction no significant increase in head loss was noted, at any velocity, for refuse concentrations up to and including the 1.1 percent level. For the inverted siphon, slight increases in head loss were found at velocities less than 1.5 feet per second for refuse concentrations of 1.0 percent. These increases disappeared at flow velocities of 2.0 feet per second and above.

2. At refuse concentrations of 1.5 percent and above, significant increases in head loss were noted through all appurtenances tested. This increase was not necessarily uniform across the velocity range but was more pronounced at either high velocities or low velocities depending on the particular appurtenance tested.

3. Heavy solids such as sand, glass and metal particles tend to settle out of the flow as the velocity is reduced. There are two significant flow velocities:

   a. Initial scouring velocity which is the minimum velocity required to clean solids by saltation as they are added at a specific rate. A steady state layer of solids may remain.

   b. Clean out velocity which is the minimum velocity required to totally remove all solids from the pipe bottom including existing accumulations of deposited solids.

4. The initial scouring and clean out velocities for each appurtenance depend strongly on the type of solids, and the rate of solids feeding. The suspended refuse concentration has a negligible effect on the velocities required.

5. Heavy metal chips require considerably higher flow velocities for adequate scouring than do sand or glass. This is particularly true of steel particles, whereas aluminum particles tend to move with the sand and glass.

6. The inverted siphon requires high velocities to carry heavy solids through the uphill leg. Because of the full flow situation in the siphon the accumulation of solids reduces the flow area, and increases the local velocity until the initial scouring velocity is reached. Thus at steady state a slight additional head loss occurs in the siphon but no blockage was experienced.

7. For manholes, the solids accumulation occurs not within the manhole but just downstream of the reduction in slope where the manhole meets the downstream pipe. The flow velocity decays in a hydraulic jump and the heavy solids settle in the pipe. In steady state the pile extends downstream until the flow velocity naturally reaches the velocity required to scour the particles in a straight pipe. Thus in steady state a long flat pile of heavy solids may be expected just beyond the manhole outlet.

8. Junctions with negligible flows in the main will collect heavy solids just upstream of a lateral. This is a transient phenomenon only since the accumulation will scour when normal flow resumes in the main.

9. Flow in pump inlets is not hampered by the addition of ground refuse in the concentrations tested. Heavy solids tested in our facility did not plug the wet well and pump inlet even when tested at concentrations on the order of 3.0 percent.

10. Flows around obstacles, sluice gates, dams and overflow wiers were not effected significantly by the addition of refuse at concentrations up to 1.5 percent. Heavy solids continued to accumulate upstream of dams and overflow weirs until dynamic equilibrium was reached where solids were added and scoured at the same rate.

Conclusions

1. In general, hydraulic transport of ground refuse in sewers at concentrations up to 1.0 percent is feasible. At very low velocities small pressure drops may occur at various appurtenances but these are not significant relative to the overall head available. At flow velocities of 2.5 feet per second and above these losses are negligible.

2. It is recommended that steel scrap be excluded from the grinder because of excessive scouring velocities required for heavy metal particles. Aluminum, glass and sand may be included.

3. Inverted siphons and manhole outlets will accumulate a stable layer of heavy solids. In the presence of grease or sewage these appurtenances may require periodic cleaning.

CHAPTER 11

RECOMMENDATIONS

The laboratory scale technical studies conducted during this program have shown that the concept of grinding household refuse and transporting it hydraulically through existing sewer lines appears to be technically feasible for the most common types of sewer applications. Certain local modifications to sewer design may be required. The economic feasibility of the overall concept of wet transport of ground refuse is presently under evaluation by Curran Associates, Northampton, Massachusetts under a separate EPA contract. Further technical work in this area would depend on the results of their study. Based on the assumption that the economics of the concept indicate feasibility of the concept, we wish to make the following recommendations for further work.

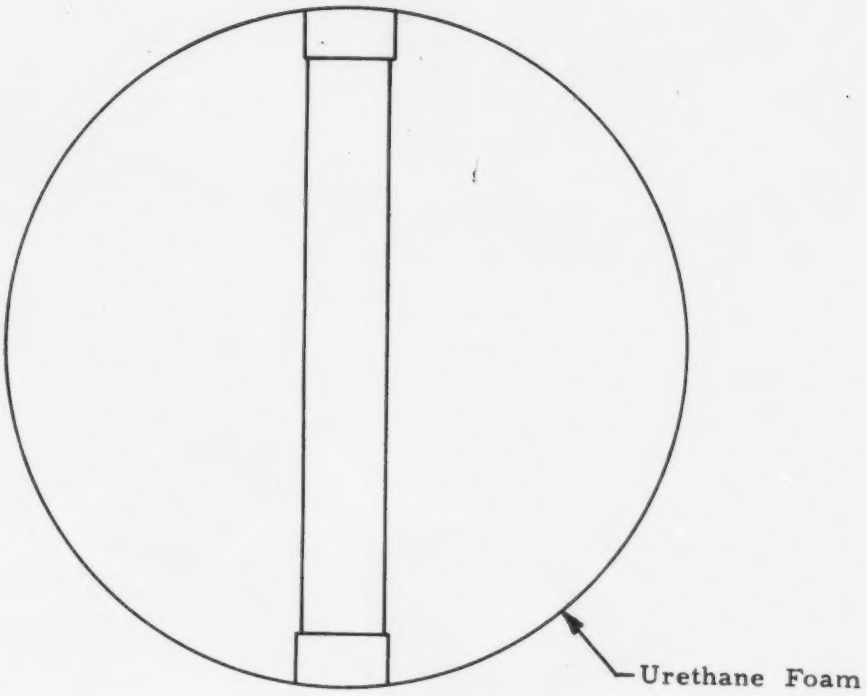
(1) To demonstrate the operation of a household refuse grinding and sewer transport system on a suitable pilot scale test loop. Such a test loop could be a few hundred feet in length and contain the normal sewer appurtenances. Refuse would be ground and admitted to the test loop at a number of points and at appropriate rates and times to simulate a community operation. The test loop would be designed to simulate the decimal variation in water flow and would be operated continuously for a period of time to observe long-term effects.

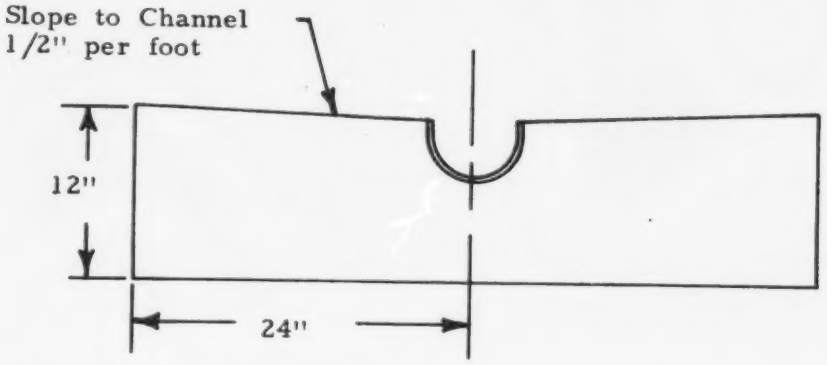
(2) An extensive laboratory and pilot scale effort to determine the treatability of the ground refuse sewage mixture.

(3) A total pilot scale operation of refuse grinding, hydraulic transport and treatment to demonstrate the operation of wet transport and treatment of household refuse.

APPENDIX A

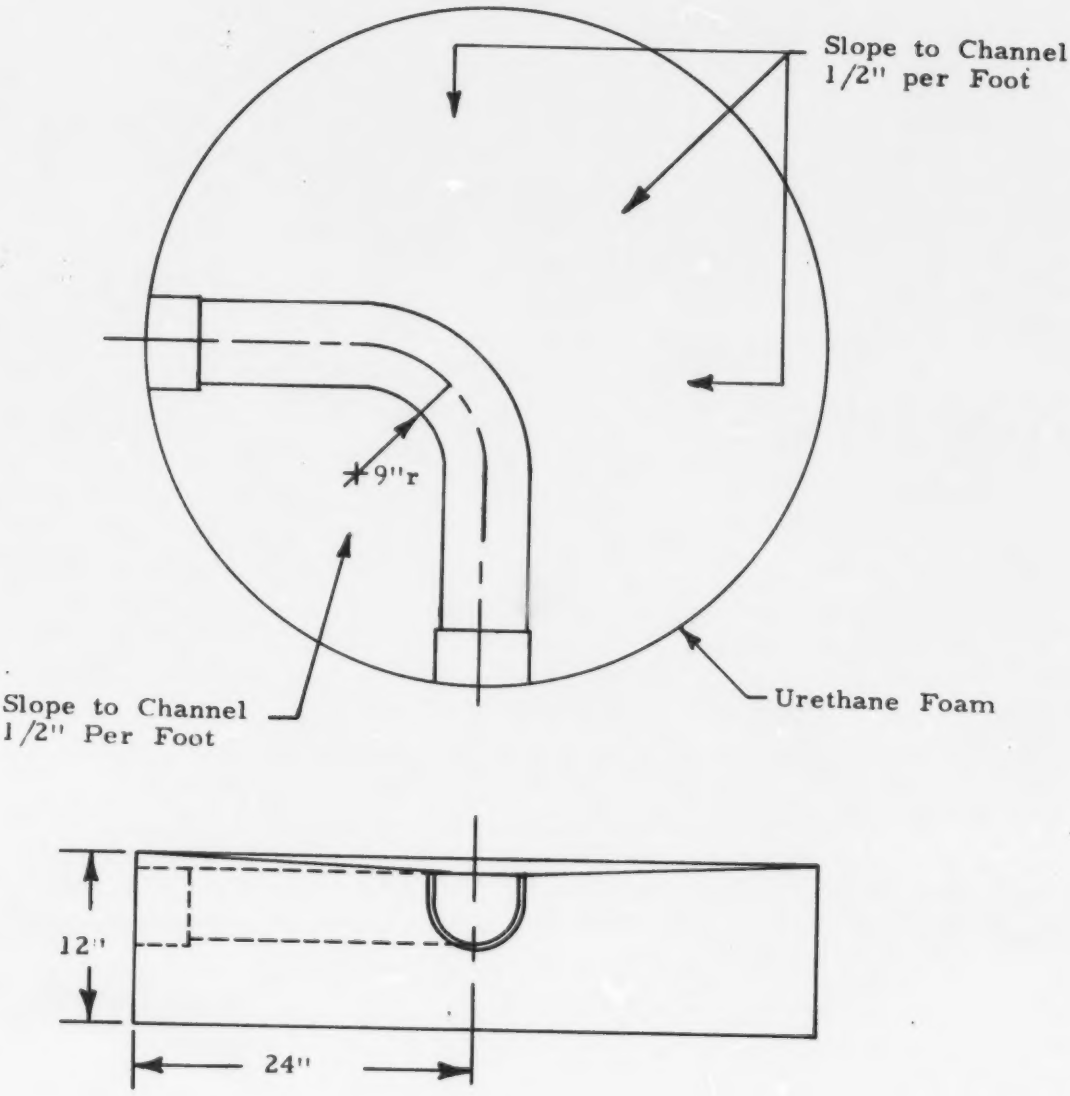
In this appendix are presented figures showing sketches of the rigid foam inserts used to simulate manhole geometries and the detailed data gathered during the manhole head loss test program. These figures are referenced in Chapter 6 of this report where the general discussion pertinent to this data is presented.





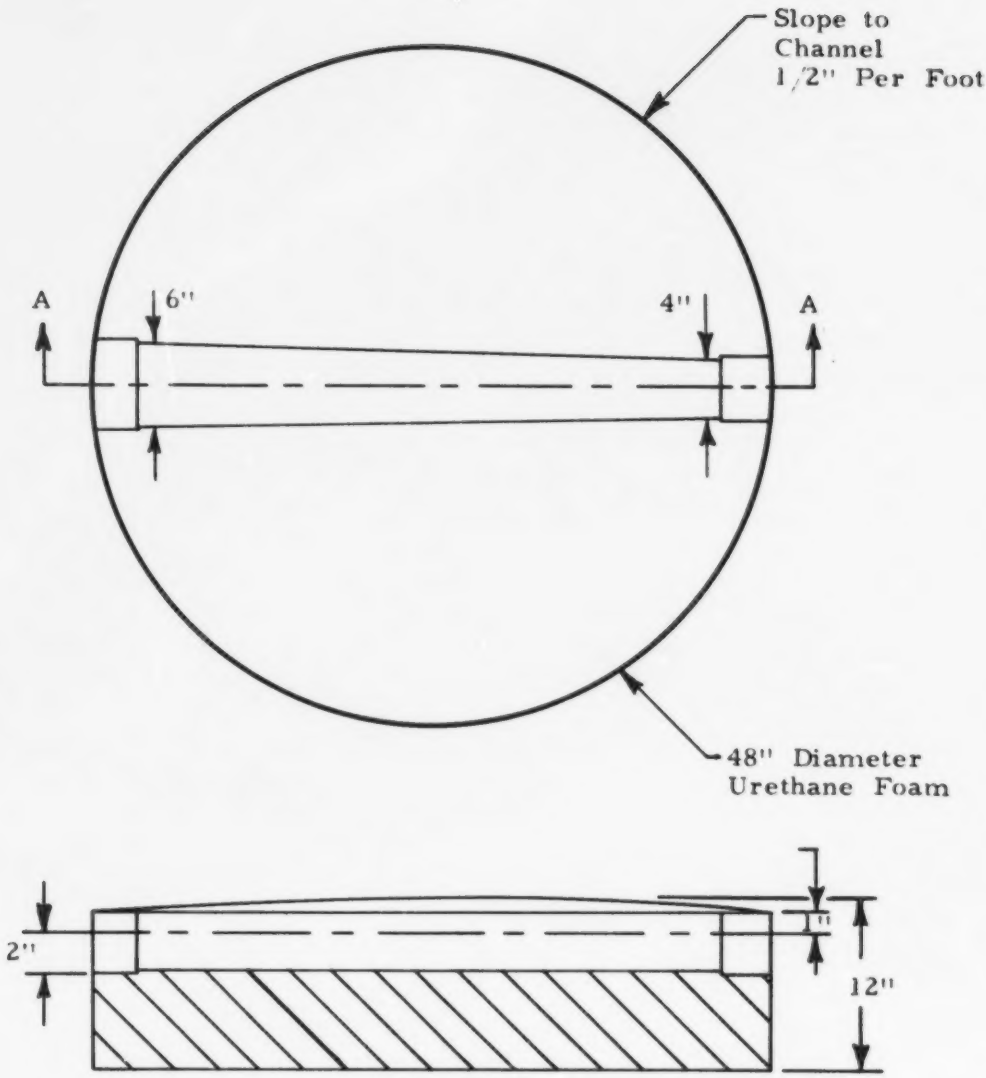
Detail of Rigid Foam Insert for Straight Thru Manhole

Figure A-1



Detail of Rigid Foam Insert for 90° Bend Manhole

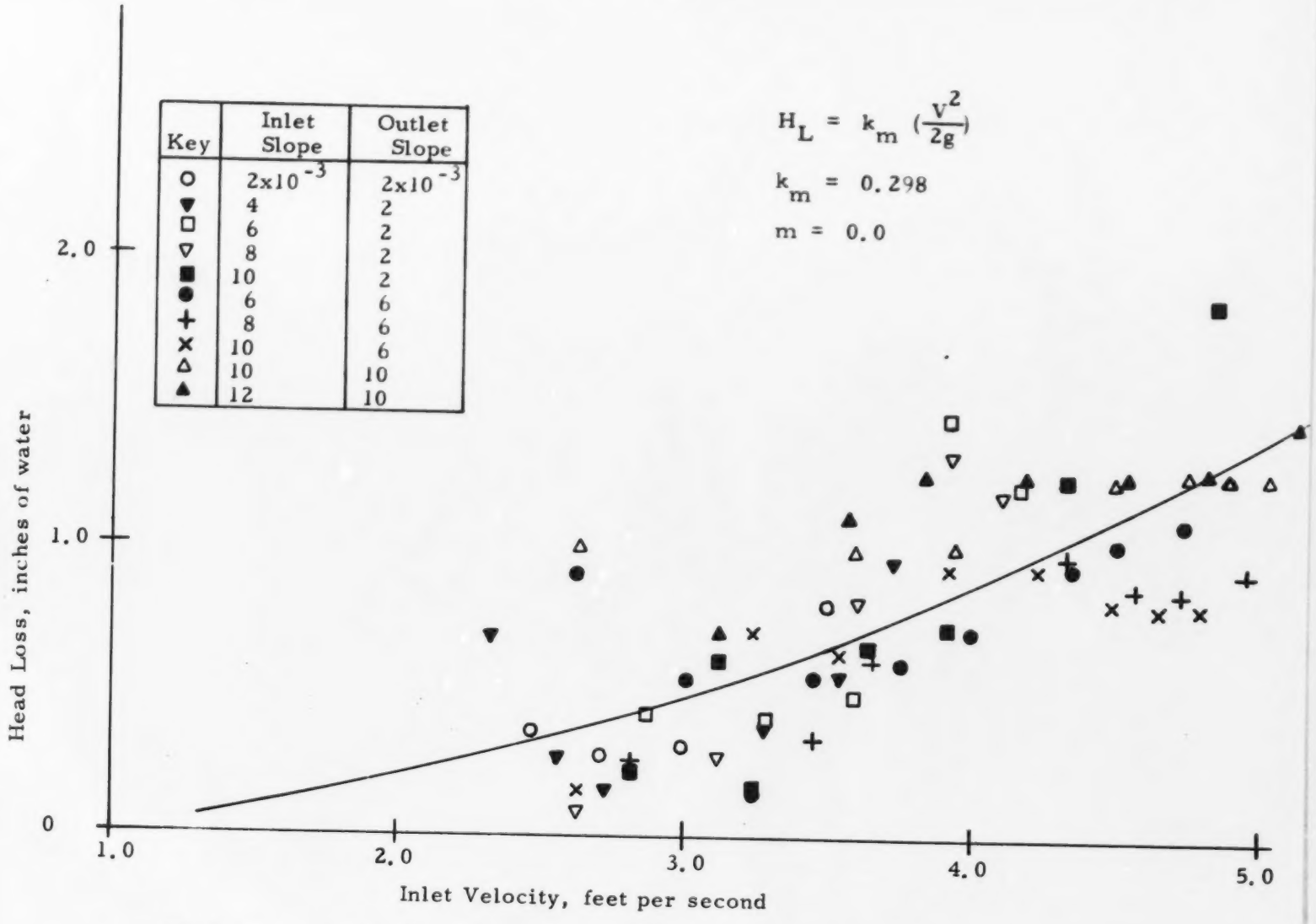
Figure A-2



Section A-A

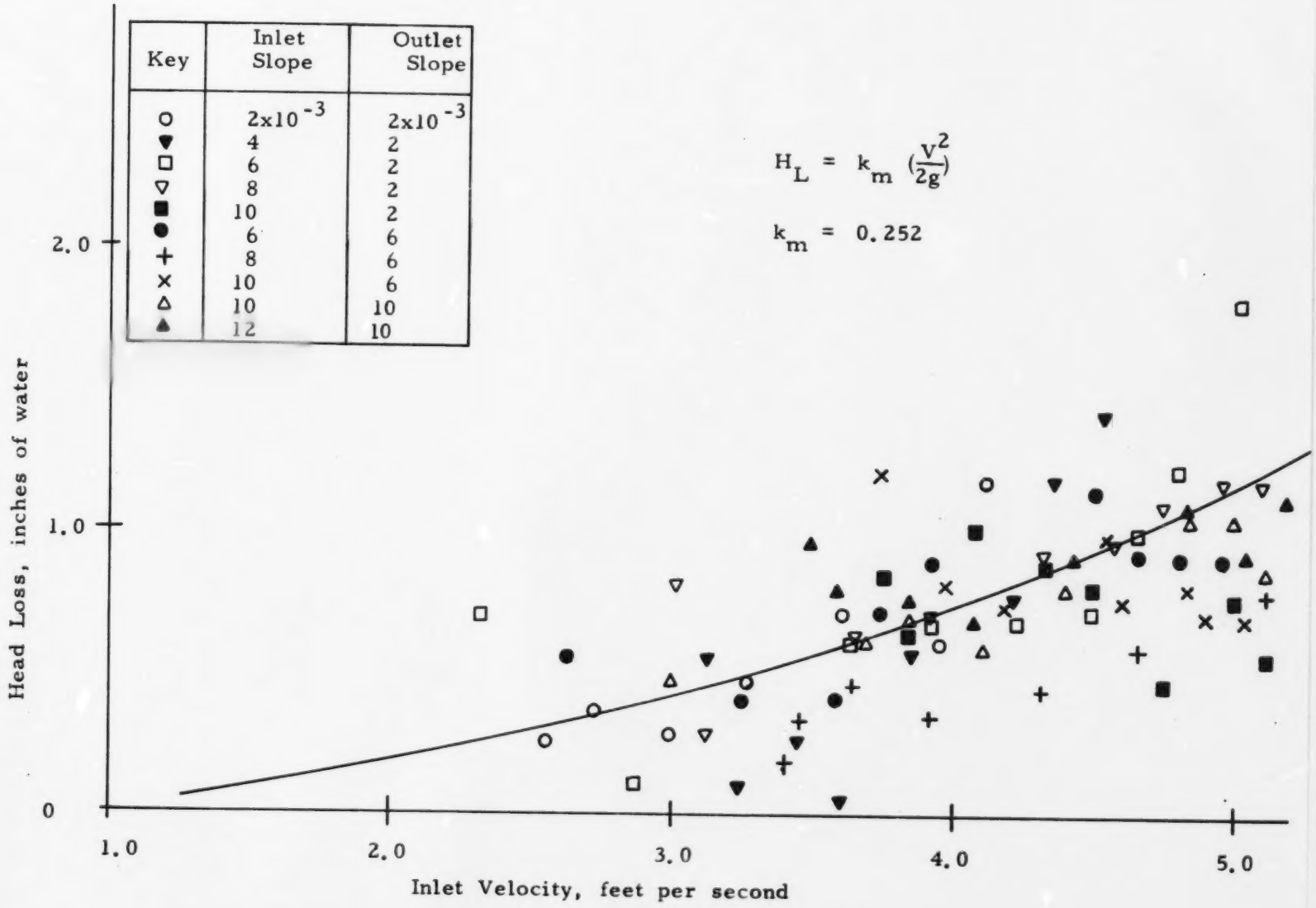
Detail of Rigid Foam Insert for Size Transition Manhole

Figure A-3



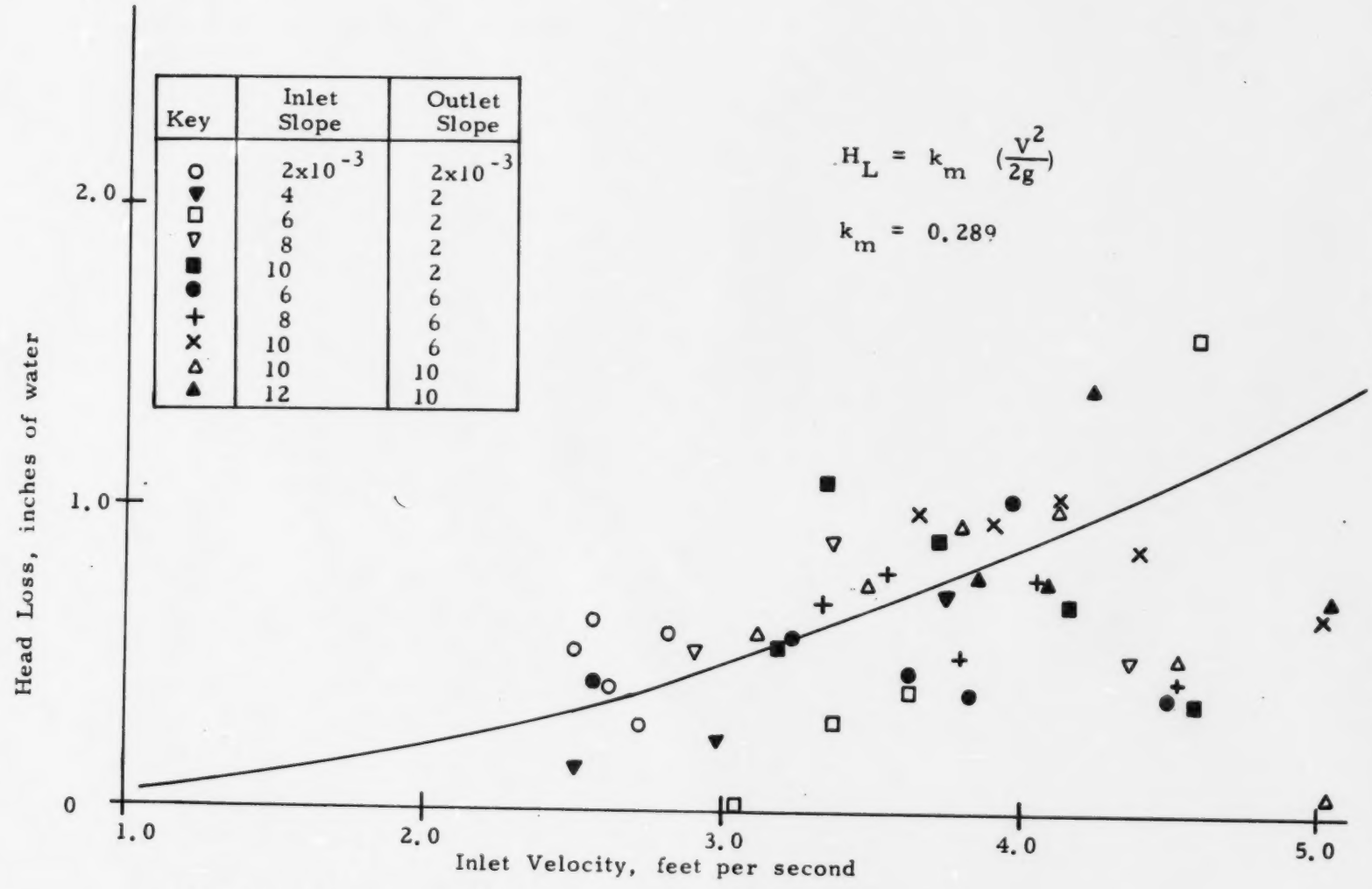
Head Loss Data for Straight Channel Manhole, Clear Water

Figure A-4



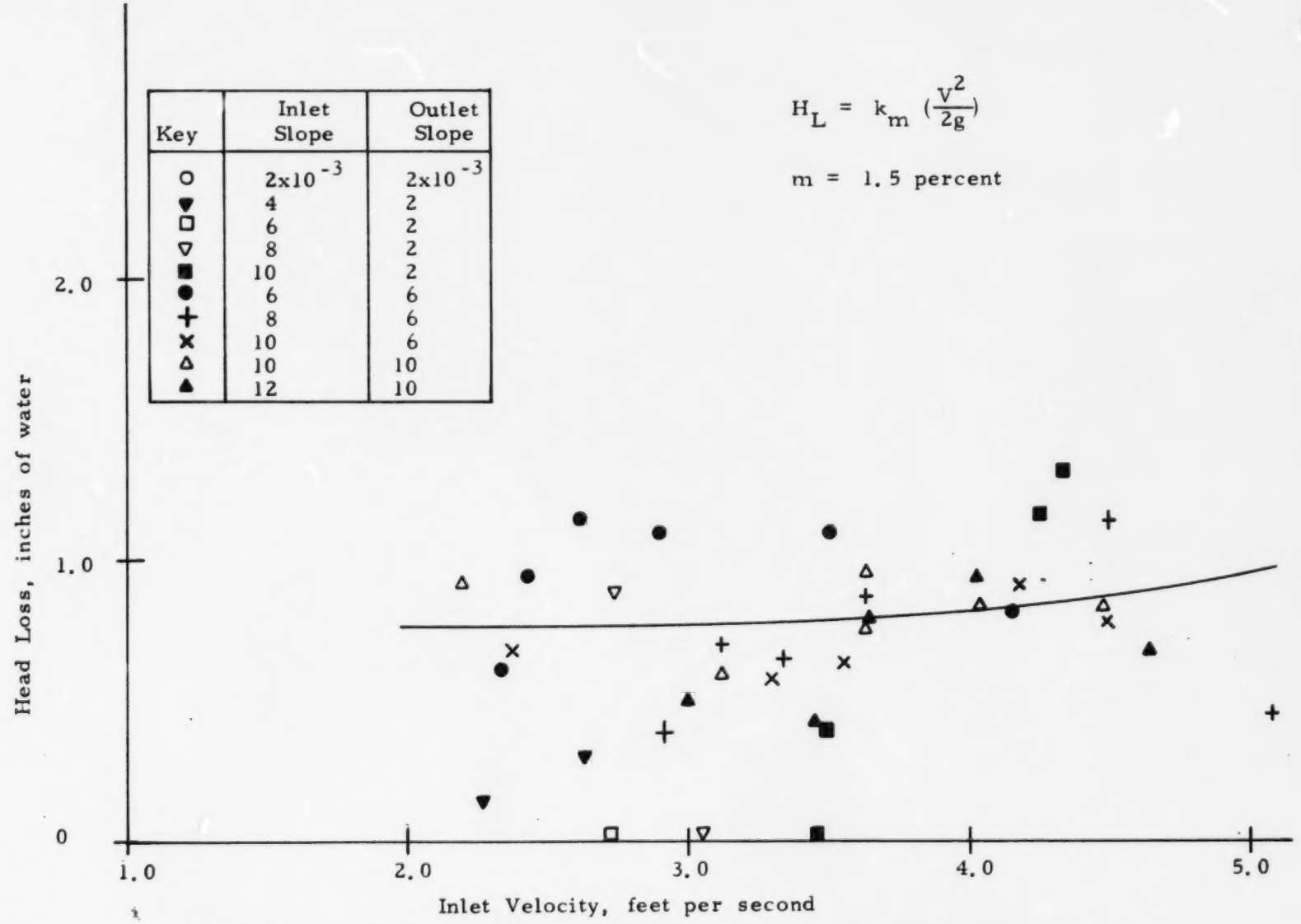
Head Loss Data for Straight Channel Manhole, 0.5 Percent Refuse

Figure A-5



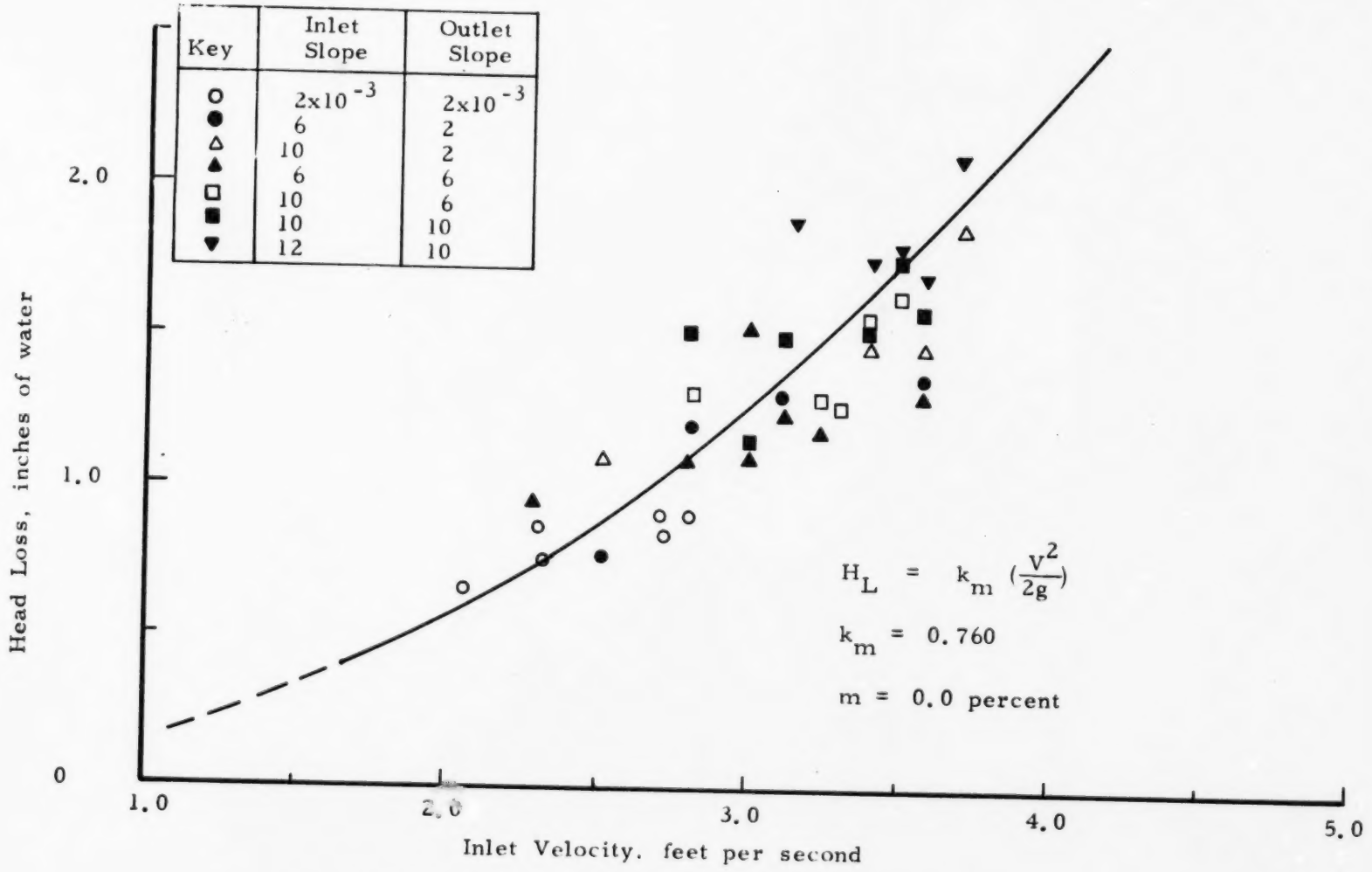
Head Loss Data for Straight Channel Manhole, 1.1 Percent Refuse

Figure A-6



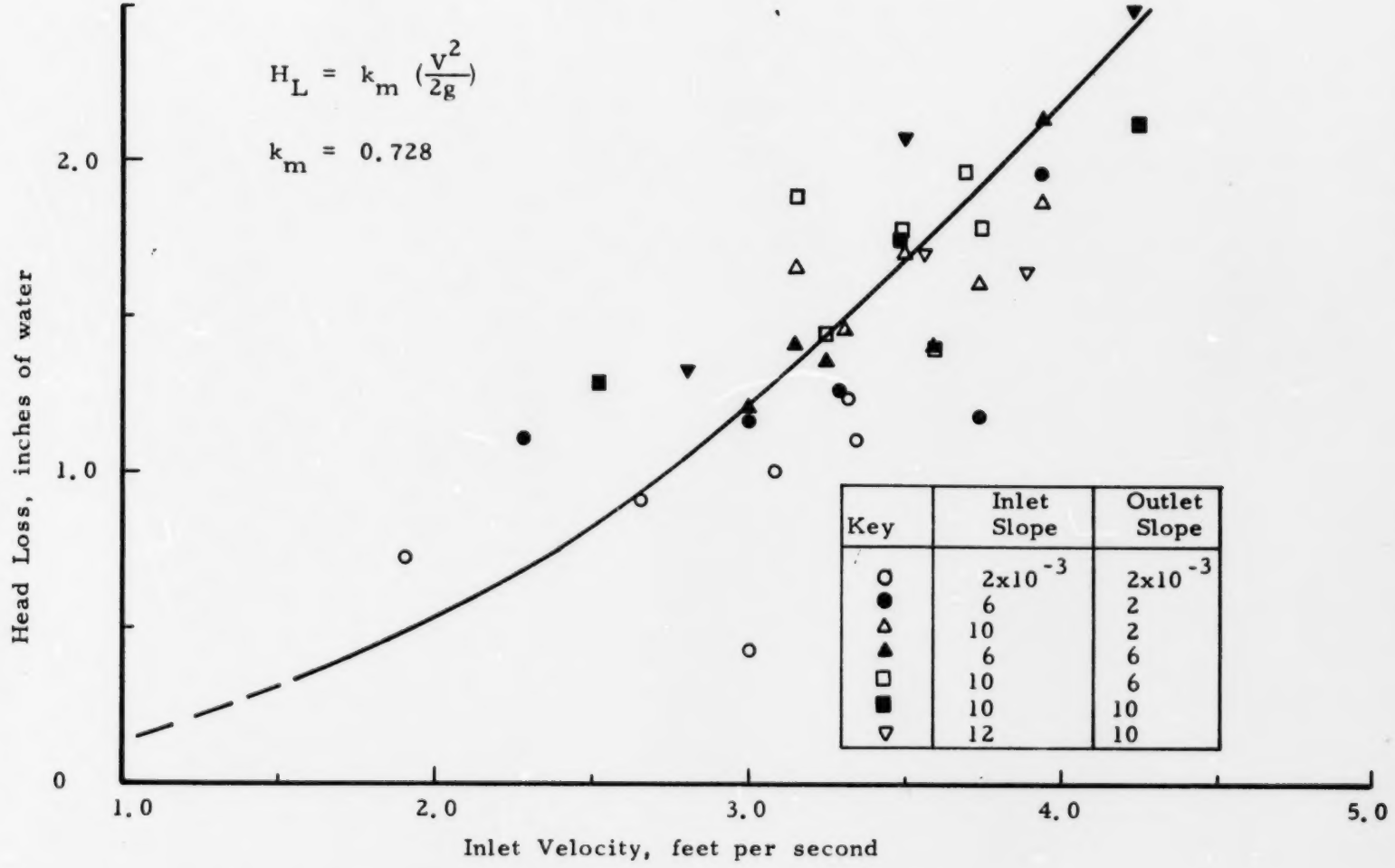
Head Loss Data for Straight Channel Manhole, 1.5 Percent Refuse

Figure A-7



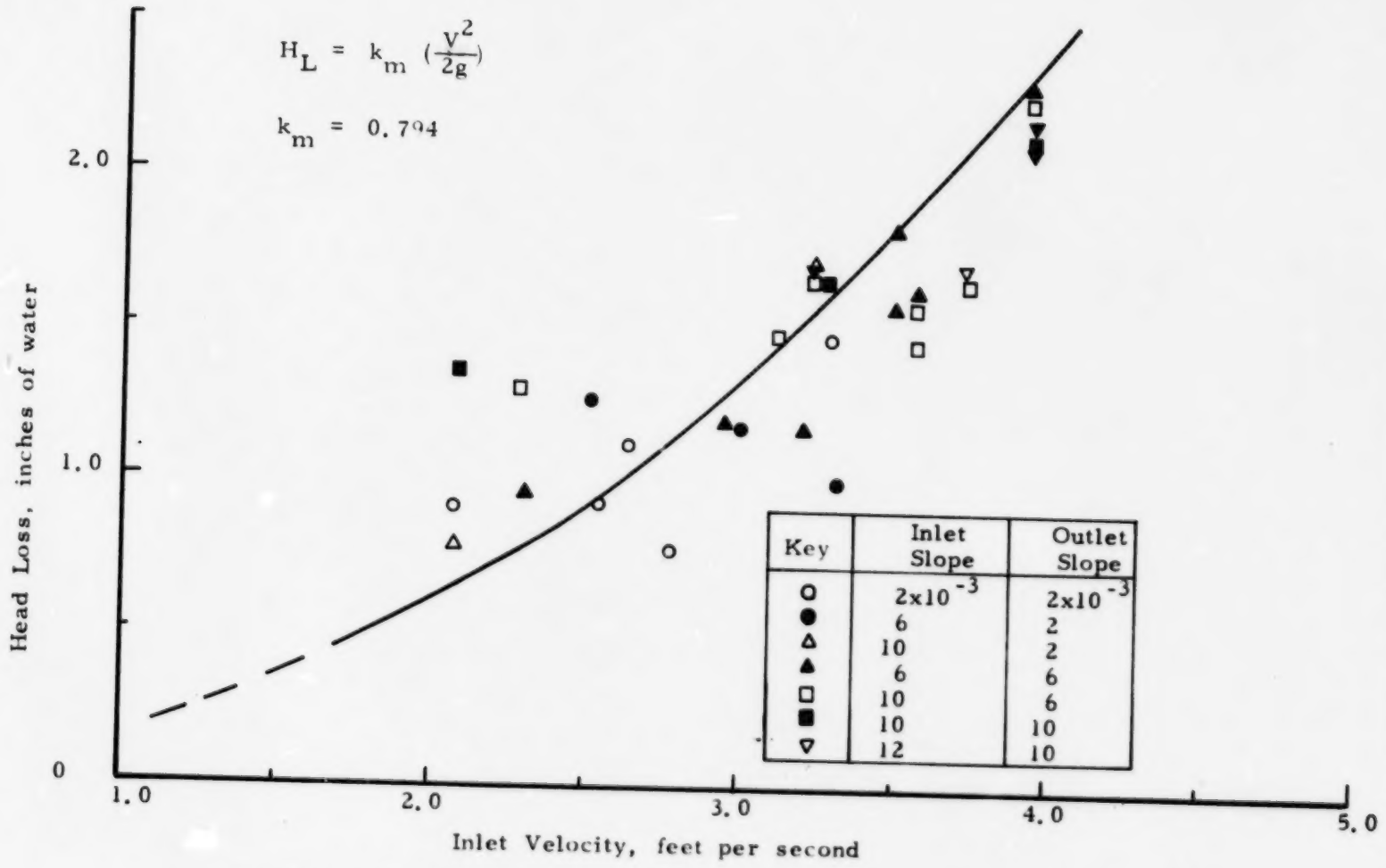
Head Loss Data for 90° Bend Manhole, Clear Water

Figure A-8



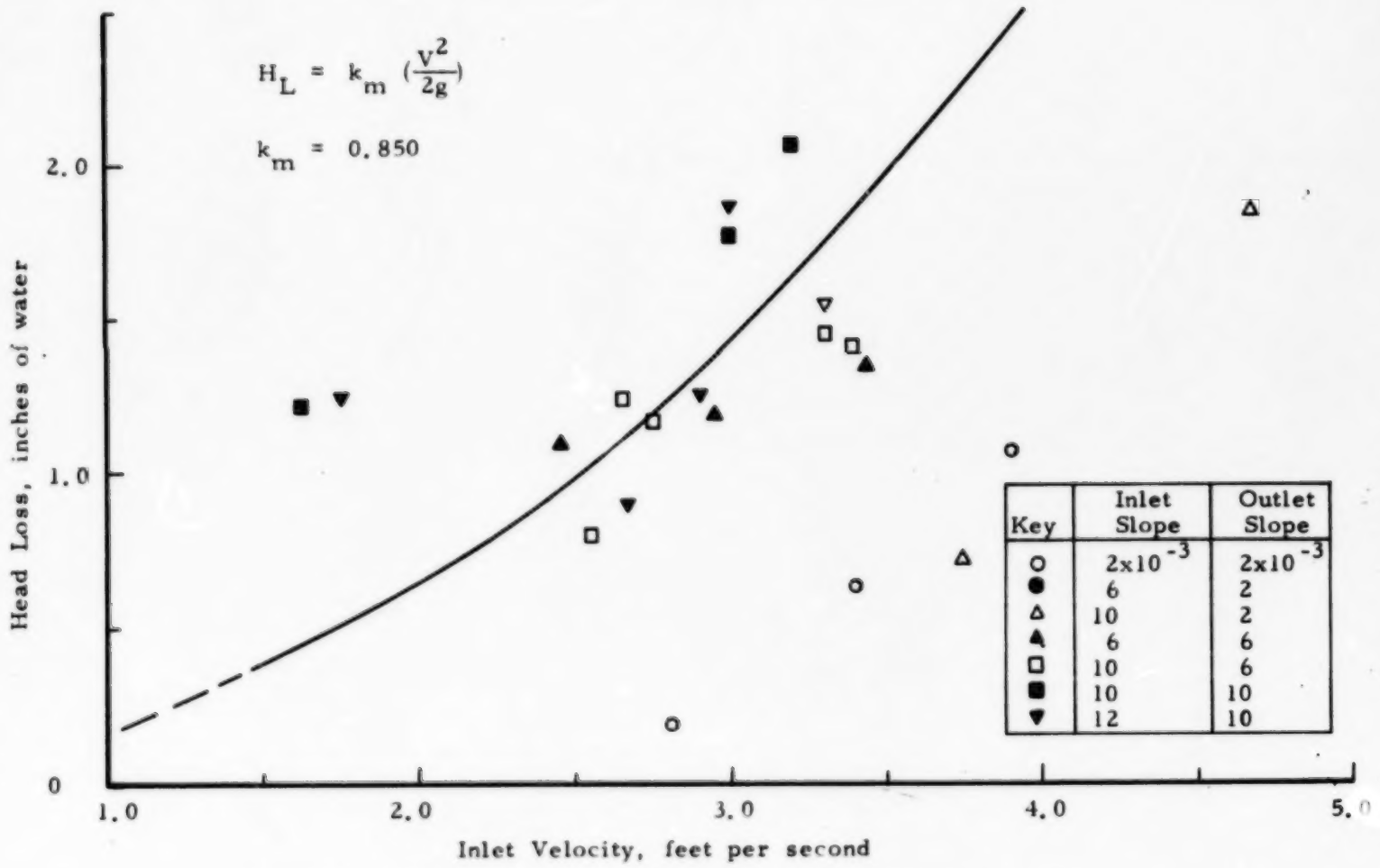
Head Loss Data for 90° Bend Manhole, 0.5 Percent Refuse

Figure A-9



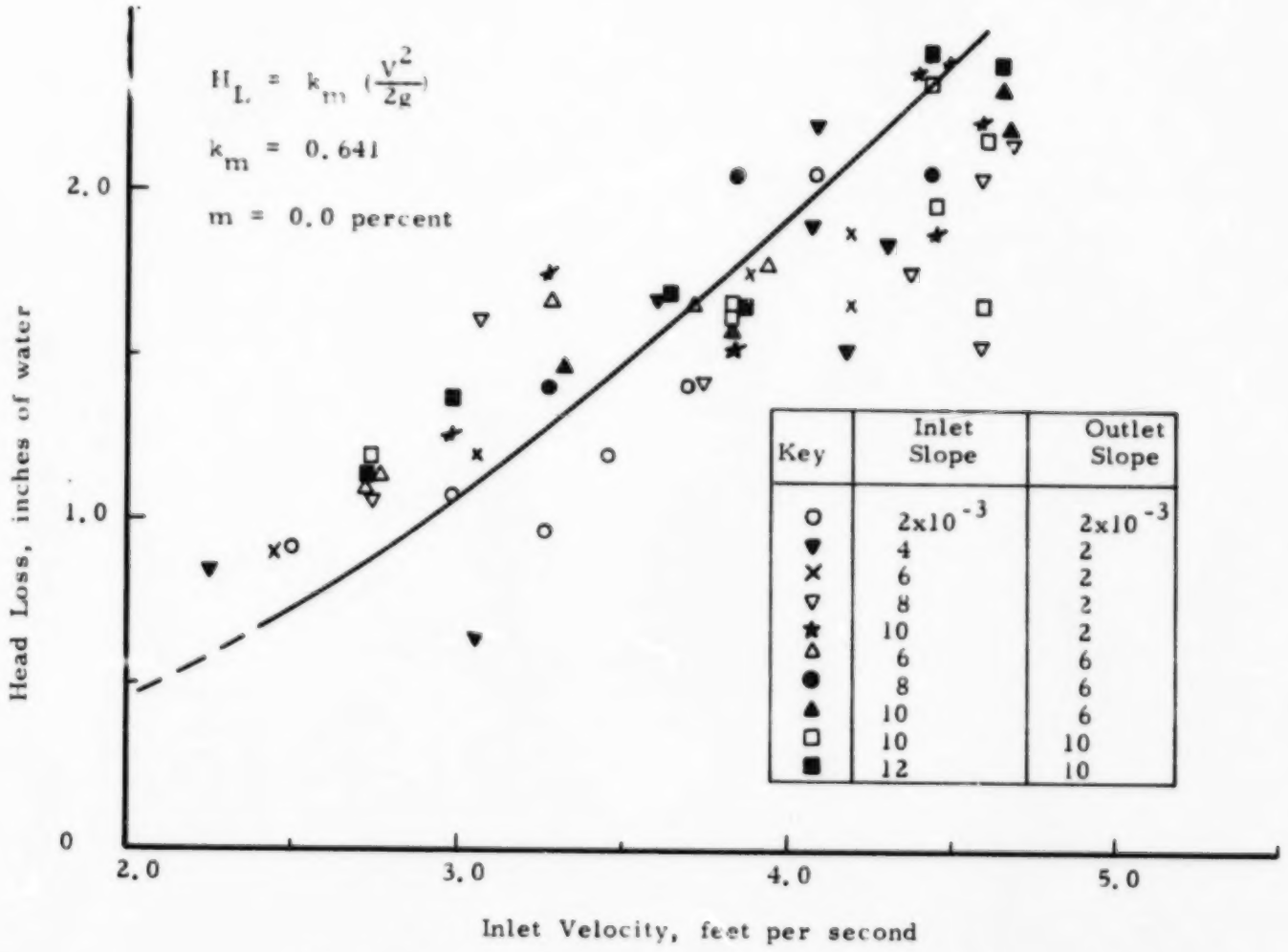
Head Loss Data for 90° Bend Manhole, 1.1 Percent Refuse

Figure A-10



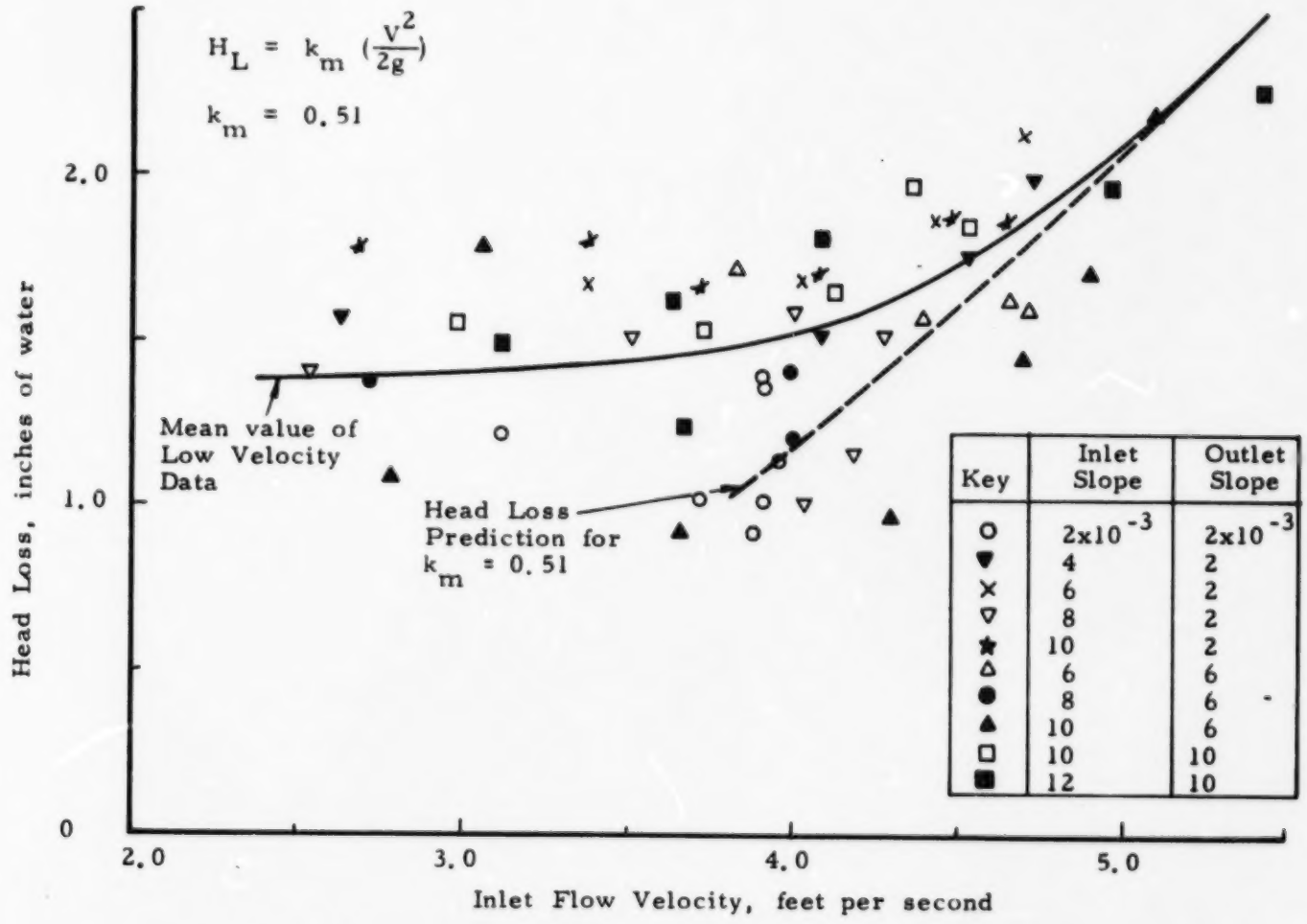
Head Loss Data for 90° Bend Manhole, 1.5 Percent Refuse

Figure A-11



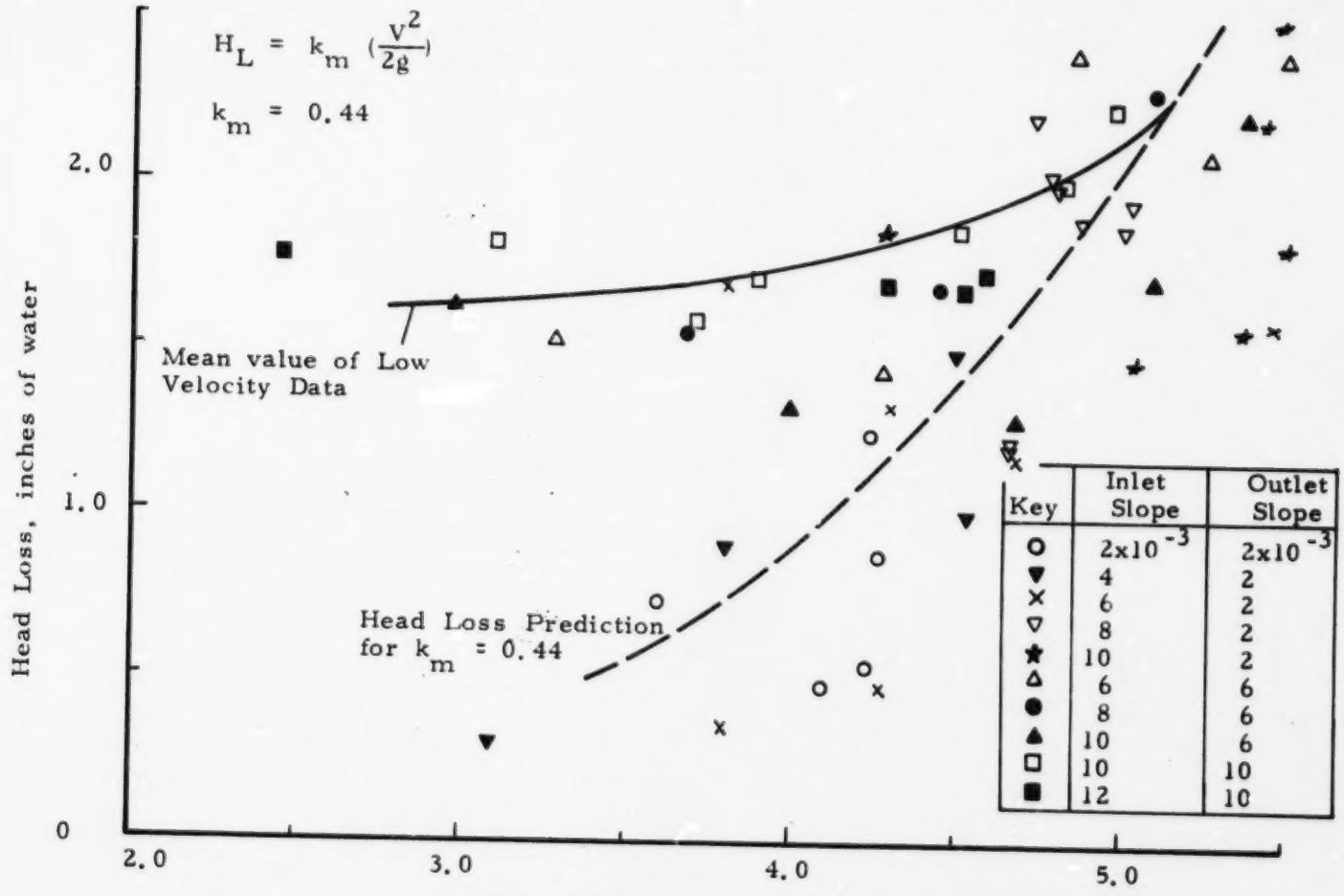
Head Loss Data for Size Transition Manhole, Clear Water

Figure A-12


$H_L = k_m (\frac{V^2}{2g})$
$k_m = 0.51$
Mean value of Low Velocity Data
Head Loss Prediction for $k_m = 0.51$
Head Loss, inches of water
Inlet Flow Velocity, feet per second
0
1.0
2.0
2.0
3.0
4.0
5.0
Key | Inlet Slope | Outlet Slope
○ | $2x10^{-3}$ | $2x10^{-3}$
▼ | 4 | 2
× | 6 | 2
▽ | 8 | 2
★ | 10 | 2
△ | 6 | 6
● | 8 | 6
▲ | 10 | 6
□ | 10 | 10
■ | 12 | 10

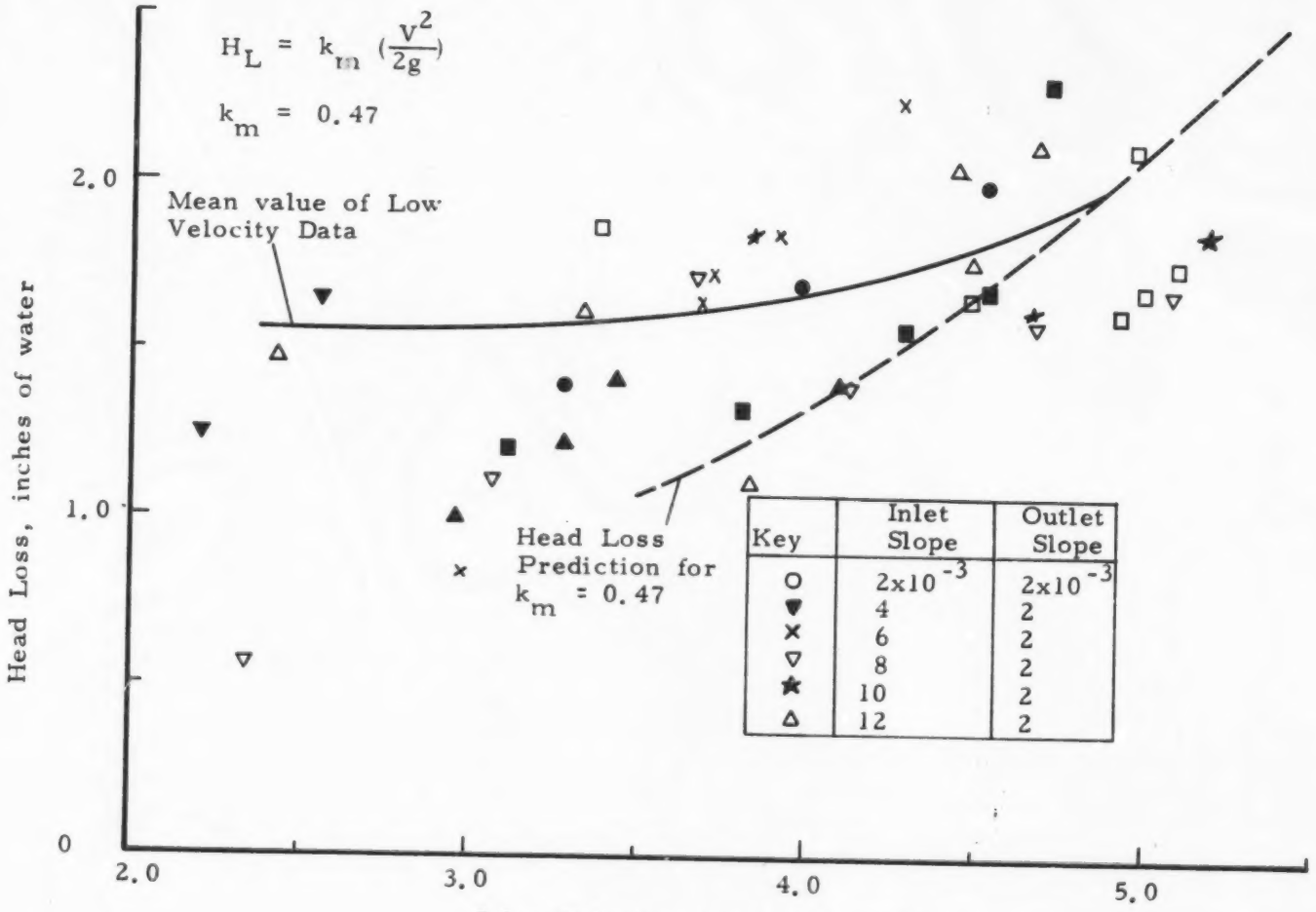
Head Loss Data for Size Transition Manhole, 0.5 Percent Refuse

Figure A-13



Head Loss Data for Size Transition Manhole, 1.1 Percent Refuse

Figure A-14



Head Loss Data for Size Transition Manhole, 1.5 Percent Refuse

Figure A-15

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3. Preliminary Design of a Household Refuse Grinder, Foster-Miller Associates, Inc., 19 January 1973.

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